

EXHIBIT A

US005912632A

United States Patent [19][11] **Patent Number:** **5,912,632****Dieska et al.**[45] **Date of Patent:** **Jun. 15, 1999**[54] **SINGLE CHIP RF TAG OSCILLATOR
CIRCUIT SYNCHRONIZED BY BASE
STATION MODULATION FREQUENCY**[56] **References Cited****U.S. PATENT DOCUMENTS**[75] **Inventors:** **David E. Dieska**, Longwood, Fla.;
Daniel Joseph Friedman, Tarrytown,
N.Y.; **Kenneth Alan Goldman**,
Norwalk, Conn.; **Harley Kent**
Heinrich, Brewster, N.Y.

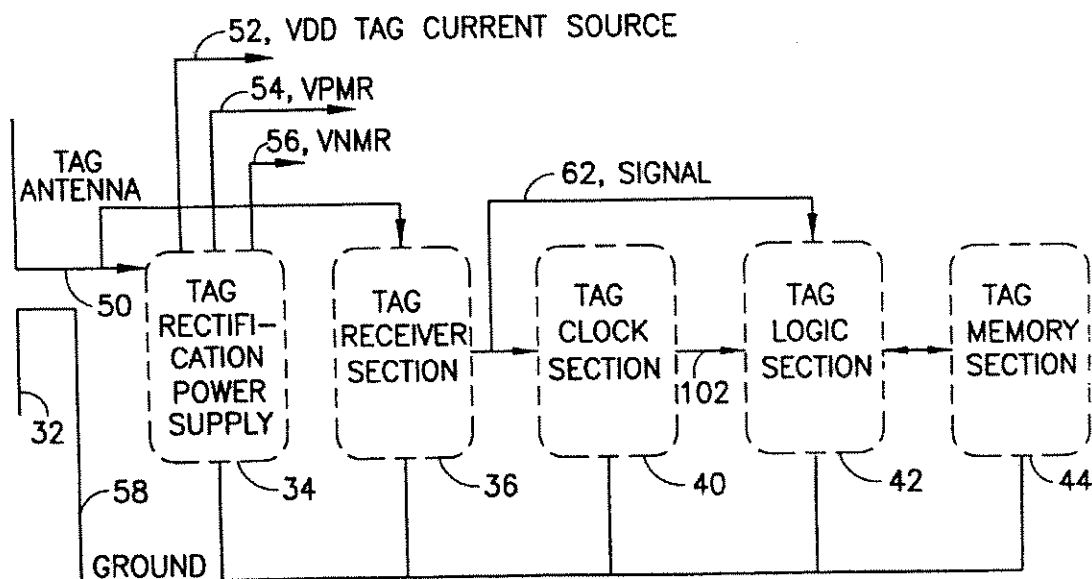
4,075,632	2/1978	Baldwin et al.	342/42
4,786,907	11/1988	Koele	342/51
5,313,198	5/1994	Hirao et al.	340/825.54
5,525,991	6/1996	Nagura et al.	342/42

[73] **Assignee:** **International Business Machines
Corporation**, Armonk, N.Y.

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Assistant Examiner—Anthony A. Asongwed
Attorney, Agent, or Firm—Rodney T. Hodgson

[21] **Appl. No.:** **08/780,765**[22] **Filed:** **Jan. 8, 1997**[51] **Int. Cl.⁶** **H04Q 5/22; H04Q 7/00;**
..... **H03L 7/00**[52] **U.S. Cl.** **340/825.54; 455/31.1;**
..... **455/37.1; 331/23; 331/10**[58] **Field of Search** **340/825.5, 825.54,**
..... **340/825.36, 825.69, 825.72; 342/51; 455/31.1,**
..... **37.1, 34.3, 38.3; 331/23**[57] **ABSTRACT**

A Radio Frequency (RF) transponder (tag), method, and system, whereby the tag has a low current tag oscillator, the oscillation frequency of the tag oscillator set by RF signal from a base station.

28 Claims, 9 Drawing Sheets.

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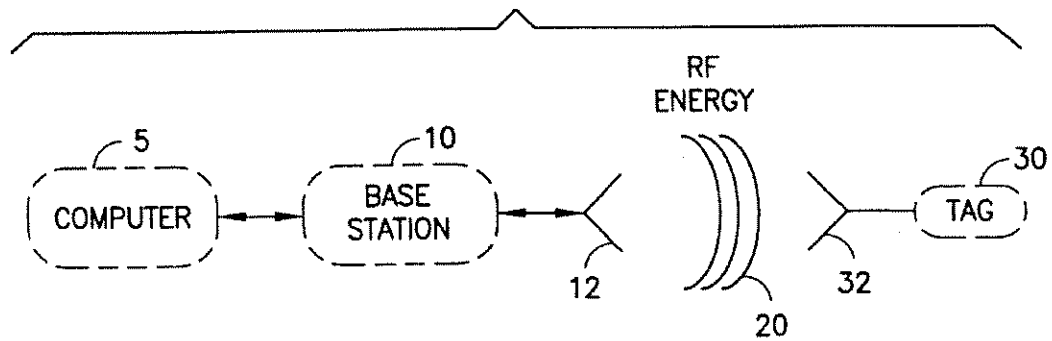


FIG. 1

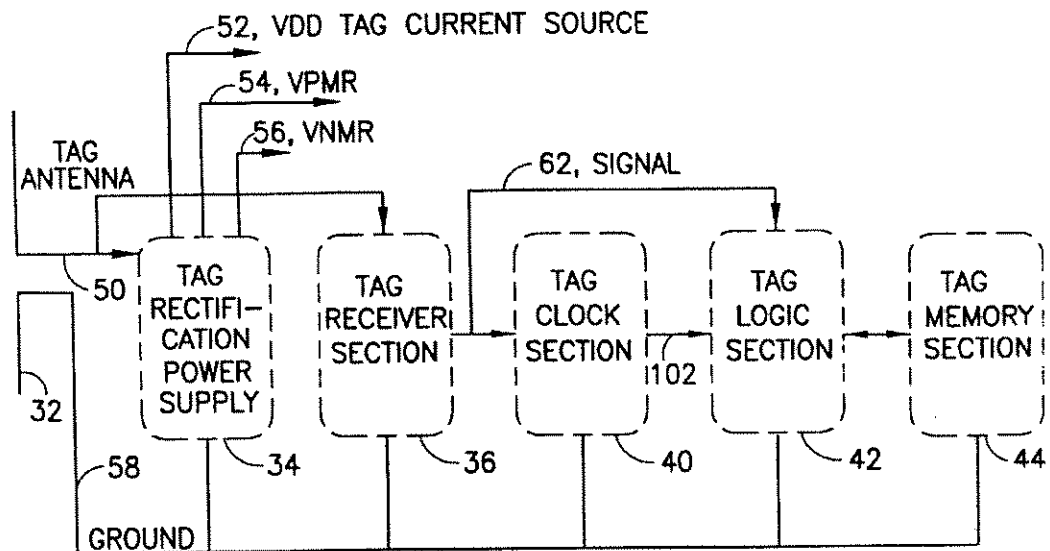


FIG. 2

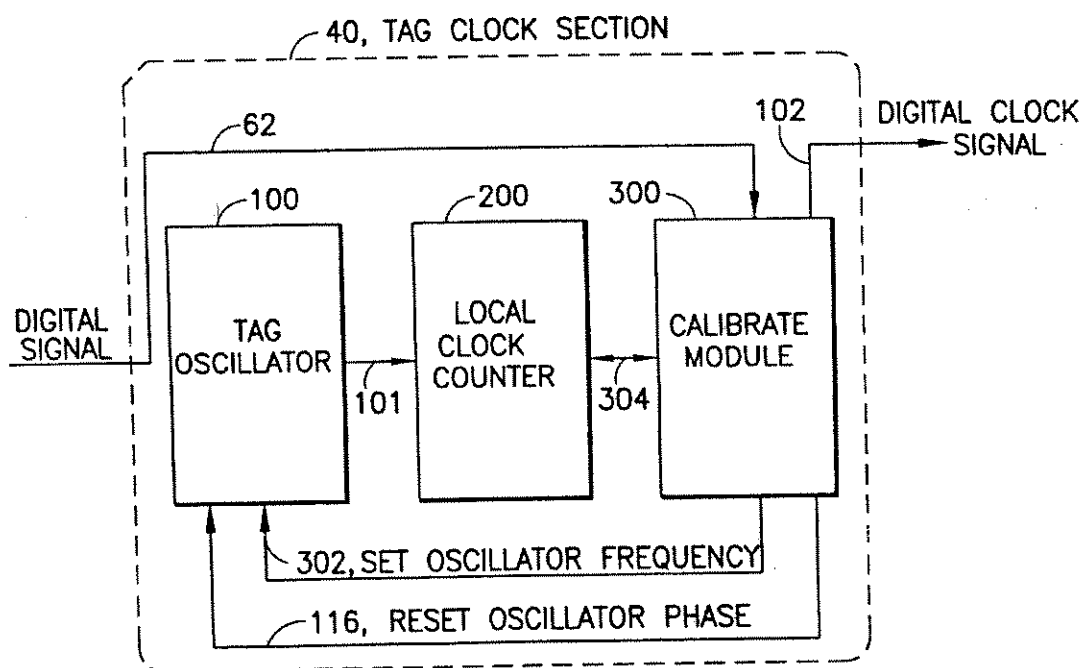


FIG.3

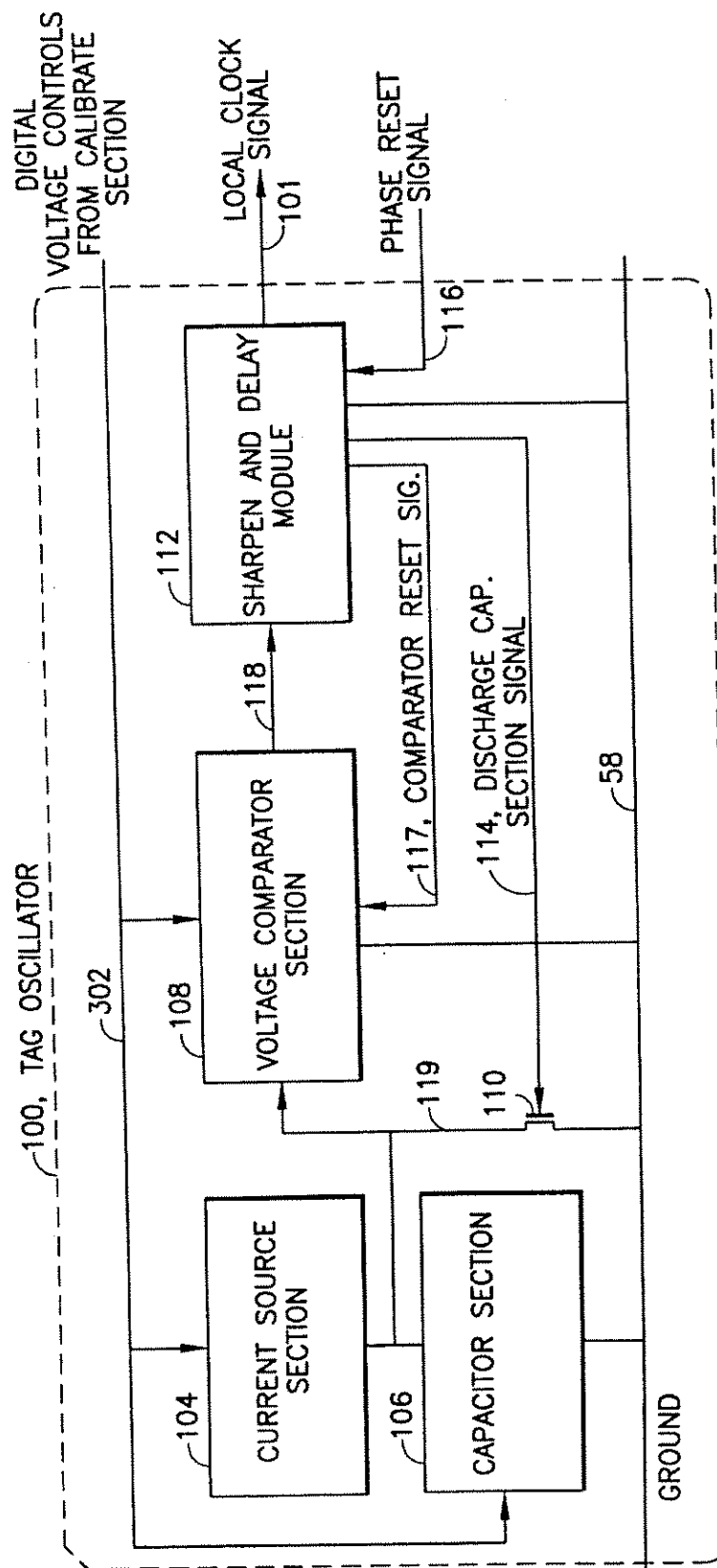


FIG. 4

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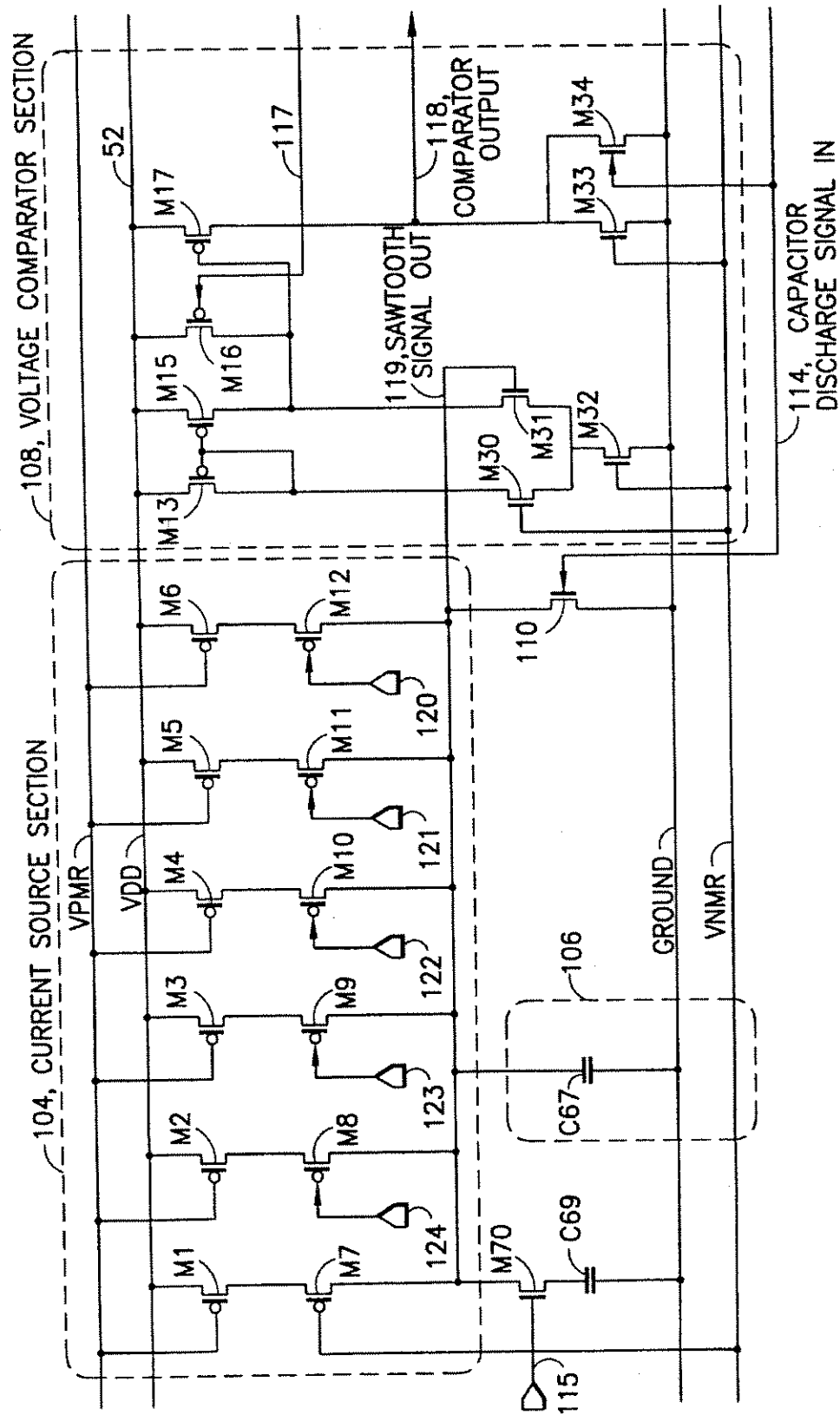


FIG.5a

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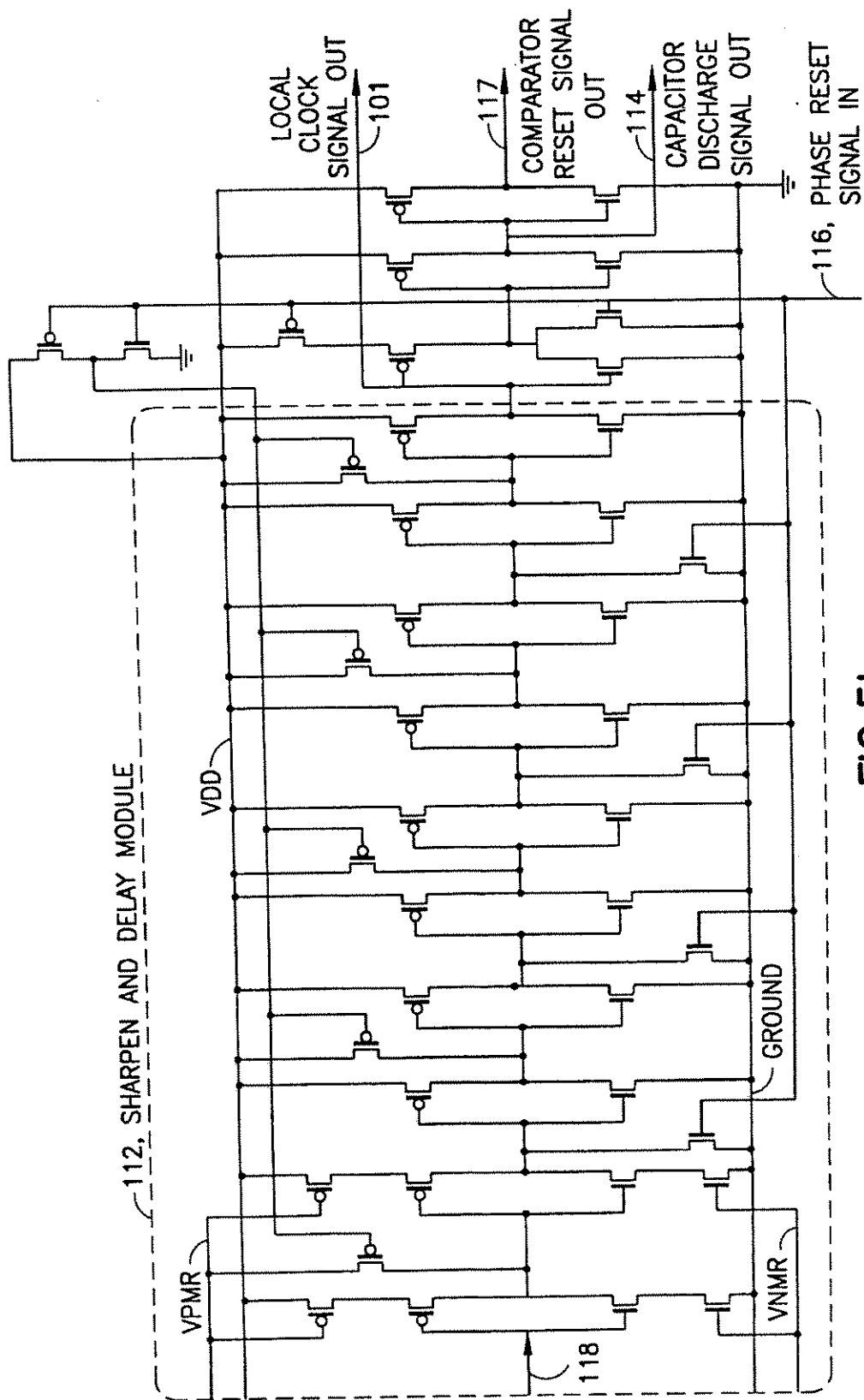


FIG.5b

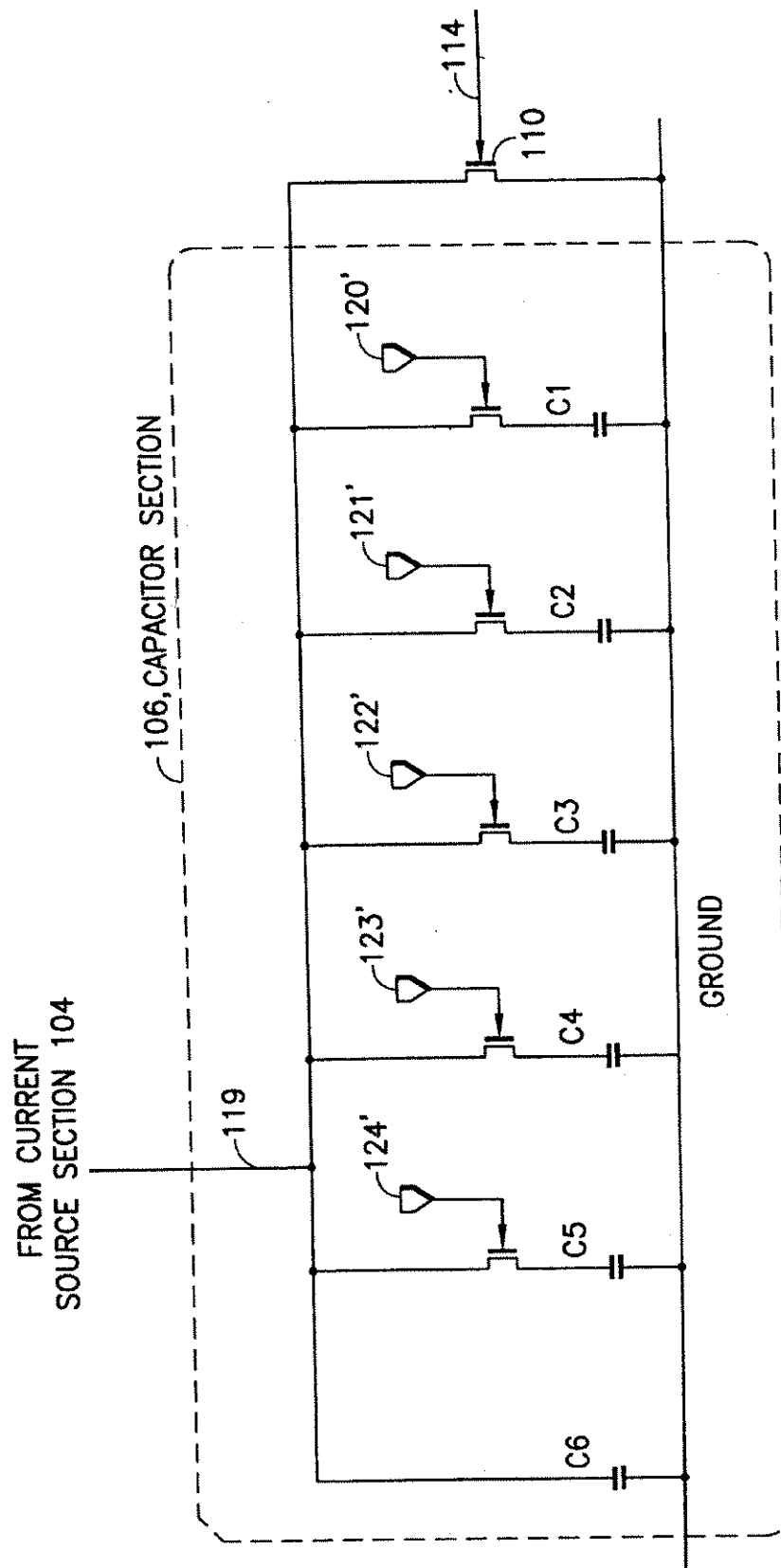


FIG.6

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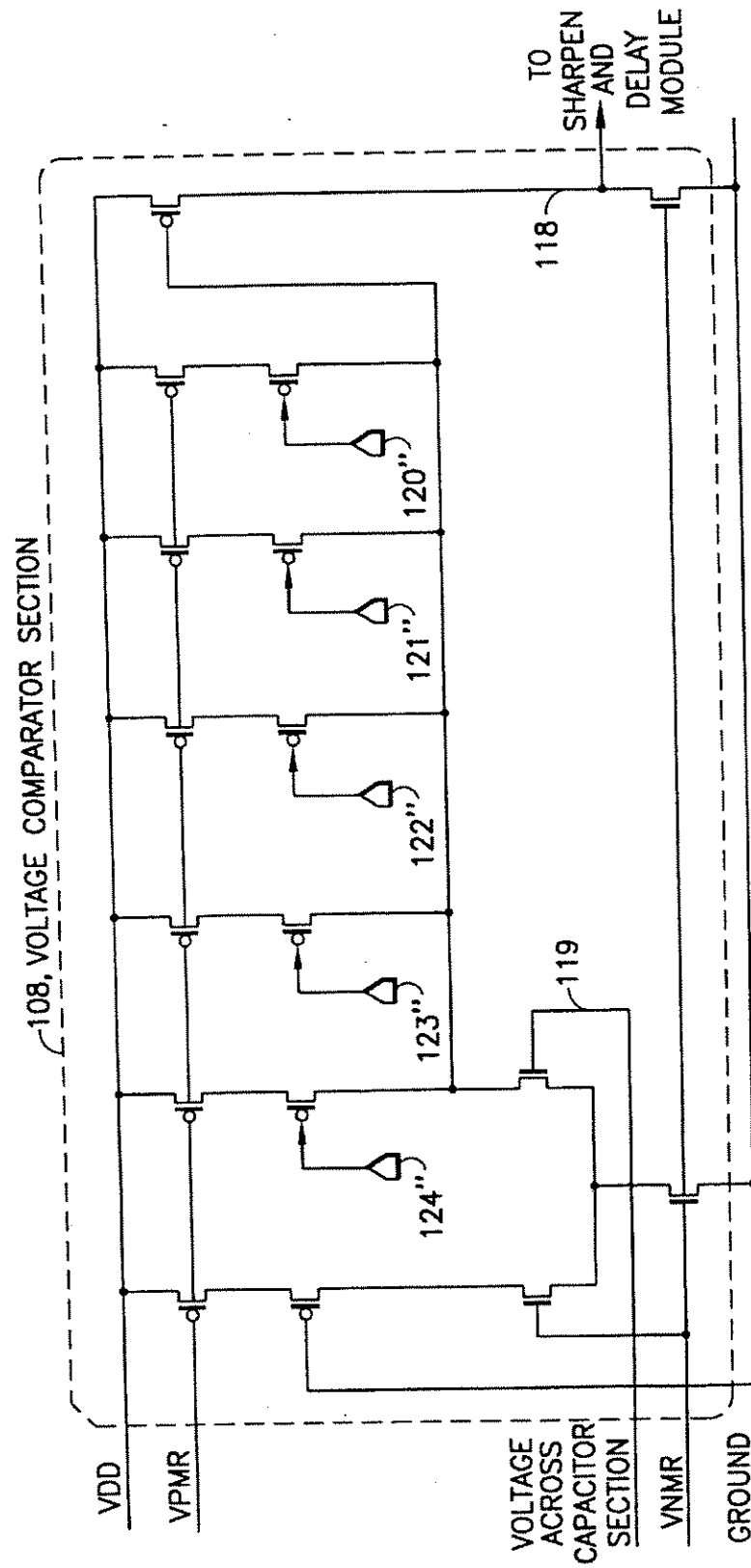


FIG.7

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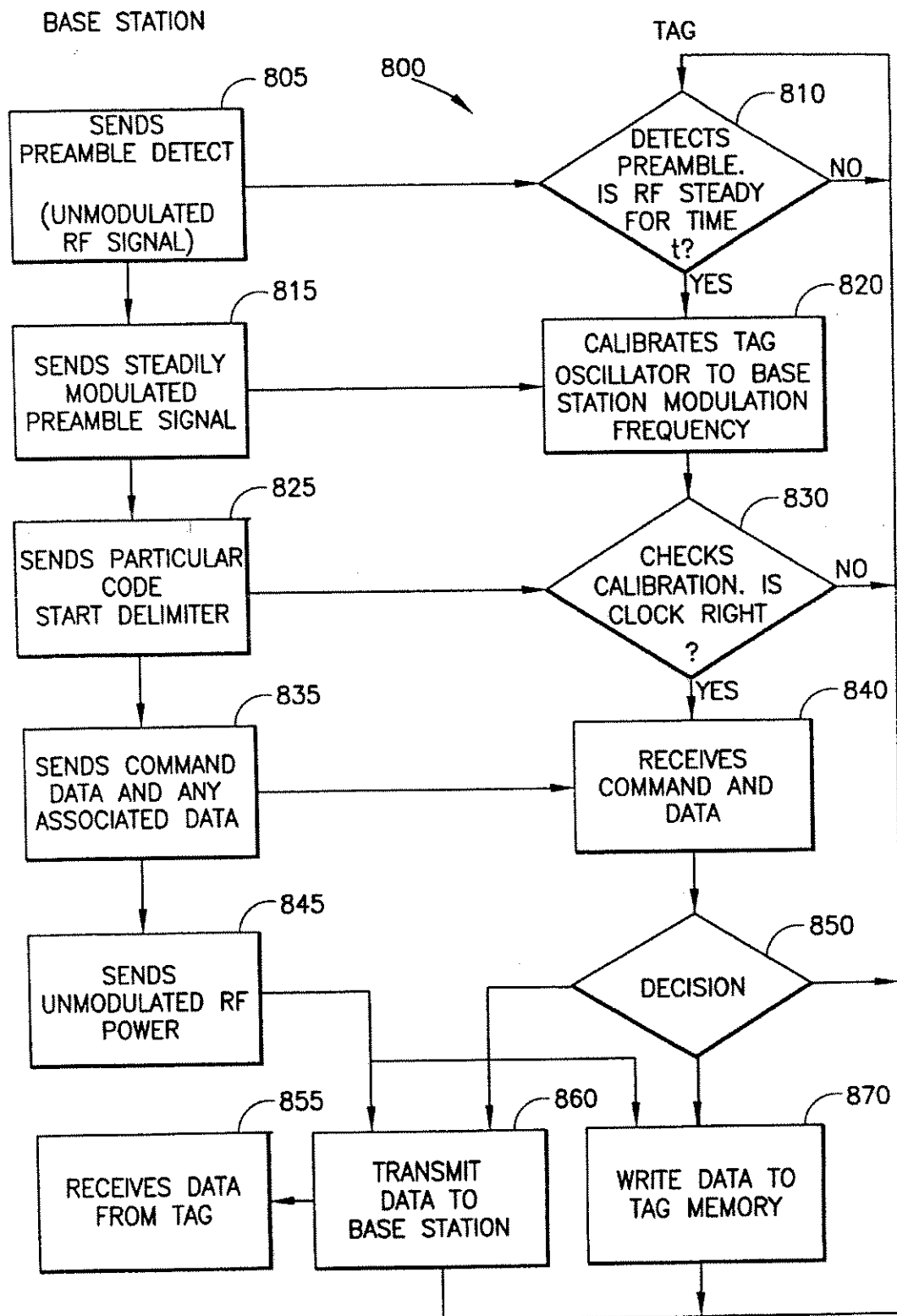


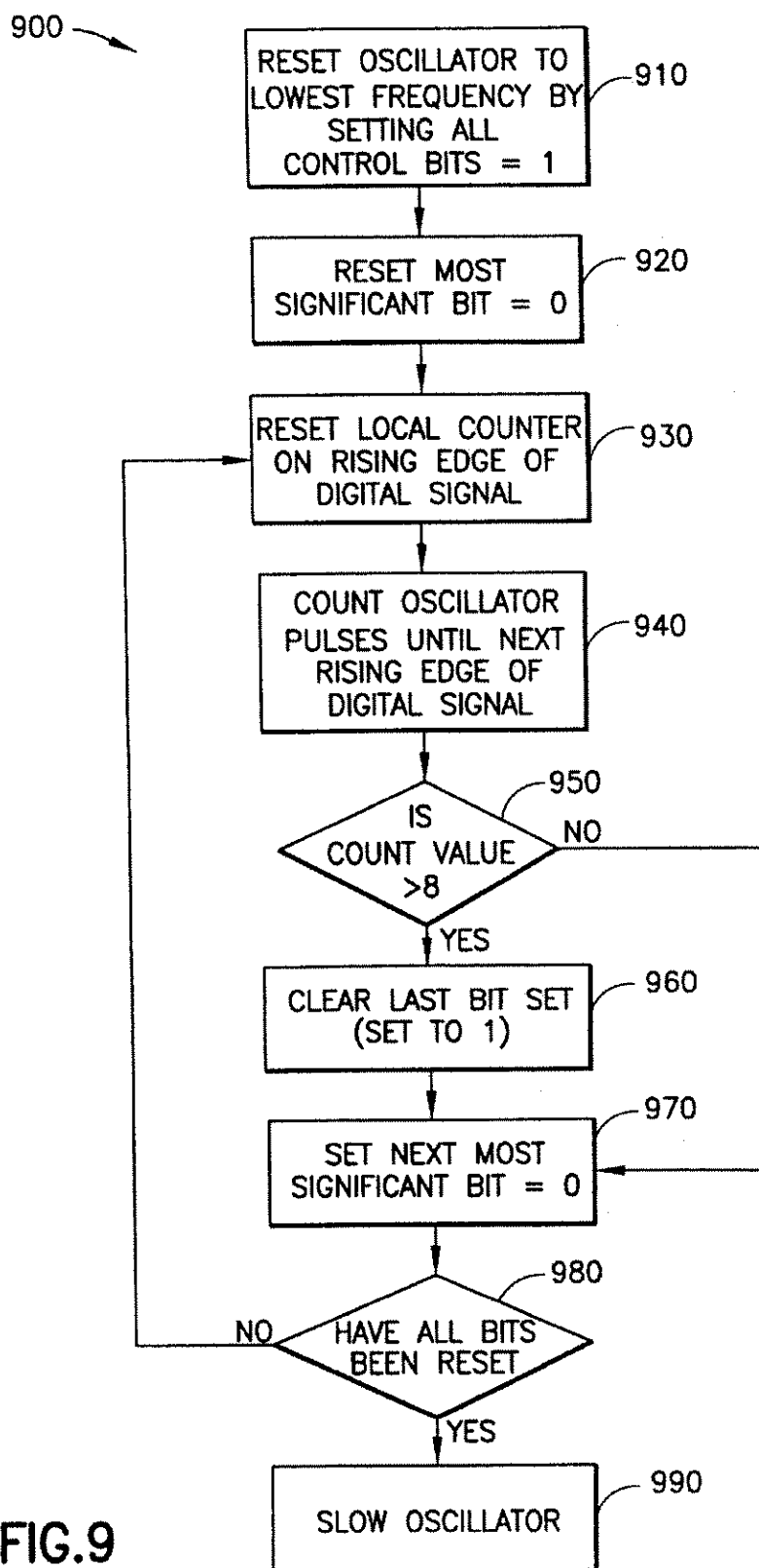
FIG.8

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SINGLE CHIP RF TAG OSCILLATOR CIRCUIT SYNCHRONIZED BY BASE STATION MODULATION FREQUENCY

FIELD OF THE INVENTION

The field of the invention is the field of Radio Frequency (RF) transponders (RF Tags) which receive RF electromagnetic radiation from a base station and send information to the base station by modulating the load of an RF antenna.

BACKGROUND OF THE INVENTION

RF Tags can be used in a multiplicity of ways for locating and identifying accompanying objects, items, animals, and people, whether these objects, items, animals, and people are stationary or mobile, and transmitting information about the state of the objects, items, animals, and people. It has been known since the early 60's in U.S. Pat. No. 3,098,971 by R. M. Richardson, that electronic components on a transponder could be powered by radio frequency (RF) power sent by a "base station" at a carrier frequency and received by an antenna on the tag. The signal picked up by the tag antenna induces an alternating current in the antenna which can be rectified by an RF diode and the rectified current can be used for a power supply for the electronic components. The tag antenna loading is changed by something that was to be measured, for example a microphone resistance in the cited patent. The oscillating current induced in the tag antenna from the incoming RF energy would thus be changed, and the change in the oscillating current led to a change in the RF power radiated from the tag antenna. This change in the radiated power from the tag antenna could be picked up by the base station antenna and thus the microphone would in effect broadcast power without itself having a self contained power supply. In the cited patent, the antenna current also oscillates at a harmonic of the carrier frequency because the diode current contains a doubled frequency component, and this frequency can be picked up and sorted out from the carrier frequency much more easily than if it were merely reflected. Since this type of tag carries no power supply of its own, it is called a "passive" tag to distinguish it from an active tag containing a battery. The battery supplies energy to run the active tag electronics, but not to broadcast the information from the tag antenna. An active tag also changes the loading on the tag antenna for the purpose of transmitting information to the base station.

The "rebroadcast" or "reflection" of the incoming RF energy at the carrier frequency is conventionally called "back scattering", even though the tag broadcasts the energy in a pattern determined solely by the tag antenna and most of the energy may not be directed "back" to the transmitting antenna.

In the 70's, suggestions to use tags with logic and read/write memories were made. In this way, the tag could not only be used to measure some characteristic, for example the temperature of an animal in U.S. Pat. No. 4,075,632 to Baldwin et. al., but could also identify the animal. The antenna load was changed by use of a transistor. A transistor switch also changed the loading of the transponder in U.S. Pat. No. 4,786,907 by A. Koelle.

Prior art tags have used electronic logic and memory circuits and receiver circuits and modulator circuits for receiving information from the base station and for sending information from the tag to the base station.

The continuing march of semiconductor technology to smaller, faster, and less power hungry has allowed enormous increases of function and enormous drop of cost of such

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tags. Presently available research and development technology will also allow new function and different products in communications technology.

Prior art tags which use a different frequency than that of the base station carrier frequency are disadvantageous in that the tag and base station antennas usually have maximum efficiency if it they are designed for a single frequency.

Prior art battery tags which use the same frequency as that of the base station must modulate the antenna reflectance with a well defined modulation frequency so that the base station can distinguish the modulated reflected signal from the various sources of noise. Prior art battery tags carry an oscillator as part of the circuitry needed to receive and send data between the tag and the base station. This oscillator needs a local frequency standard to fix the tag modulation frequency so that the base station can easily and cheaply receive and demodulate the modulated signal sent by the tag. Such local frequency standards are very expensive and hard to integrate on a monolithic semiconductor chip. The tags require an oscillator which draws a lot of current from the tag power supply, either from a battery tag or a passive tag, which lowers either the life of the battery or the range of the tag, respectively. In addition, the base station may have to adjust to the modulation frequency sent out by the tag, which requires that the base station listens to the tag in the first step of the communication procedure, instead of talking to the tag first. This complicates communication procedures when there are multiple tags in the field. Each tag may be sending signals to the base station with a different modulation frequency, and the signals will interfere.

RELATED APPLICATIONS

Copending patent applications assigned to the assignee of the present invention and hereby incorporated by reference, are:

Ser. No. 08/303,965 filed Sep. 9, 1994 entitled RF Group Select Protocol, by Cesar et. al now U.S. Pat. No. 5,673,037;

Ser. No. 08/304,340 filed Sep. 9, 1994 entitled Multiple Item RF ID protocol, by Chan et. al. now U.S. Pat. No. 5,550,547;

Ser. No. 08/521,898 filed Aug. 31, 1995 entitled Diode Modulator for RF Transponder by Friedman et al. now U.S. Pat. No. 5,606,325;

application submitted Aug. 9, 1996 entitled RFID System with Broadcast Capability by Cesar et al.; and

application submitted Jul. 29, 1996 entitled RFID transponder with Electronic Circuitry Enabling and Disabling Capability, by Heinrich et al.

OBJECTS OF THE INVENTION

It is an object of the invention to produce an RF transponder comprising circuits which can be made at low cost. It is a further object of the invention to produce an RF transponder which can be used at high frequencies. It is a further object of the invention to produce an RF transponder with maximum range. It is a further object of the invention to produce an RF transponder with circuits which require very little current. It is a further object of the invention to produce an electronic chip for an RF transponder which can be produced simply with standard semiconductor manufacturing techniques. It is a further object of the invention to produce a communication system for communicating with the RF transponder of the present invention. It is a further object of the invention to produce a system for controlling

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the communication system using the present invention. It is a further object of the invention to produce a system for using and changing information received from the transponder of the present invention.

SUMMARY OF THE INVENTION

The present invention is to have a passive RF tag with a tag oscillator with an oscillation frequency which the tag can lock to a signal sent from the base station to the tag. An innovative low current oscillator design accomplishes this invention. Innovative low current ancillary circuits are also provided. The preferred signal is the modulation frequency of the modulated RF signal that the base station sends to the tag. In this way, an expensive local frequency standard on the tag is not needed, and an inexpensive oscillator can be constructed solely from the transistors and capacitors which are easily and cheaply made on a single chip RF tag. The base station is also cheaper, since the tag sends information modulated at a frequency related to the modulation frequency of the base station, and the base station does not have to have an expensive oscillator circuit which tracks wide excursions of the tag modulation frequency. The result is better noise performance since the base station looks in a much narrower frequency band for the tag signal than would otherwise be the case with inexpensive oscillator circuits on the tag.

BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1. A system of a base station and an RF tag.
- FIG. 2. A block diagram of part of the RF tag.
- FIG. 3. A block diagram of the tag clock section.
- FIG. 4. A block diagram of a preferred tag oscillator.
- FIG. 5a. and 5b. A circuit diagram for a preferred embodiment of a tag oscillator.
- FIG. 6. A circuit diagram for an alternative preferred embodiment of a capacitor section for a tag oscillator.
- FIG. 7. A circuit diagram for an alternative preferred embodiment of a voltage comparator section for a tag oscillator.
- FIG. 8. A flow chart of a preferred method of implementing and using the apparatus of the invention.
- FIG. 9. A flow chart of a preferred method of calibrating the tag oscillator.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a system of a base station 10 having an associated computer 5 sending RF energy 20 from base station antenna 12 to a tag antenna 32 associated with an RF tag 30. The RF frequency f_0 is preferably above 100 MHz, more preferably above 900 MHz, and most preferably above 2,300 MHz. The RF signal is preferably amplitude modulated at a frequency f_1 greater than 1 KHz, more preferably between 5 and 150 kHz, and most preferably between 20 and 60 kHz. However, the RF signal may also be modulated by frequency modulation or by phase modulation methods, as is well known in the art of RF signal propagation. The RF tag 30 may be a passive tag which receives all the energy needed to carry out the tag functions from the RF field broadcast by the base station, or it may be an active tag which carries a battery to store the required energy. An active tag may, and a passive tag will, change the loading on the tag antenna 32 to change the antenna reflectivity and thus communicate with the base station 10.

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FIG. 2 shows a block diagram of the tag antenna 32 and part of the RF tag 30. (Neither a possible RF tag transmitter section nor other sections such as measurement sections nor alarm section nor enable/disable sections are shown.) The RF antenna 32 feeds RF power to the tag rectification power supply 34. A battery tag would replace block 34 with a battery (not shown). In the preferred embodiment shown in FIG. 2, a tag rectification signal receiving section 36 comprising an RF diode, a signal capacitor, and a signal capacitor current drain is separate from the tag rectification power supply, but the oscillator section of the invention is also contemplated in the case that section 36 is part of the tag rectification power supply 34. The tag power supply 34 supplies current at voltage VDD on line 52, and optionally supplies voltages VPMR, and VNMR on lines 54 and 56 respectively. These lines are used to power and control the various devices on the tag. The RF antenna 32 has two connections to the tag 30, denoted here by lines 50 and 58. Line 58 is the conventional ground.

The tag rectification signal receiving section 36 receives an RF signal which is preferably amplitude modulated at a frequency f_1 from the antenna 32 over line 50, and rectifies and demodulates the RF signal and delivers a digital signal to the rest of the tag electronics over line 62. If the RF is modulated with a steady modulation frequency f_1 , the output of the signal receiving section 36 is preferably a series of square pulses of unit voltage at a frequency f_1 . However, any pattern or subpattern in the signal sent out from the base station could be used to generate an output of the signal receiving section 36 in order to adjust the frequency and optionally the phase of the tag oscillator.

The tag clock section 40 receives the digital demodulated digital signal from line 62 and sets the tag oscillator frequency using the modulation frequency f_1 of the modulated RF signal as will be explained later.

The tag clock section 40 delivers a digital clock signal on line 102 to the tag logic section 42, to the tag memory section 44, and to other tag electronic sections as needed.

FIG. 3 is a block diagram of the tag clock section 40. The tag oscillator 100 must use less than 500 microamperes of current from the tag power supply 34 in order to avoid drawing down the tag voltage VDD and lowering the range of the tag. It is more preferred that the tag oscillator uses less than 50 microamperes of current. It is even more preferred to have the tag oscillator draw less than 5 microamperes of current when the tag oscillator is oscillating with maximum oscillation frequency, and less than 150 nanoamperes of current when the tag oscillator is oscillating with minimum frequency. In a preferred embodiment, the tag oscillator 100 comprises an oscillator with a block diagram given later in FIG. 4.

The tag oscillator frequency is set by the voltages supplied by a connection denoted 302 from a calibrate module 300. The tag oscillator 100 supplies a local clock signal to the local clock counter 200 over line 101. The local clock counter 200 counts the clock ticks of the local clock signal since the local clock counter 200 has been reset and passes the count to the calibrate module 300 via a connection 304. The calibrate module 300 resets the local clock counter 200 via the connection 304 (and optionally resets the phase of the oscillator 100 over connection 116) on a rising edge of the digital input signal on line 62, and sets the voltages controlling the frequency of oscillator 100 to give a set number of counts between two rising edges of the digital input signal 62 when the base station 10 is sending a steadily modulated RF signal. The calibrate module 300 sends the voltages

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controlling the frequency of the oscillator 100 over line 302. The oscillator 100 frequency is thus determined by the modulation frequency of the RF energy 20 transmitted by the base station 10. While the calibrate module may carry out its functions using a rising edge of the digital input signal, it is clear to one skilled in the art that the falling edge of the digital signal, or indeed any characteristic of the signal on line 62, may serve as well. The calibrate module sends the digital clock signal to the rest of the tag electronics over line 102.

FIG. 4 is a block diagram for an oscillator section 100. A current source section 104 charges a capacitor section 106. The voltage across capacitor section 106 on line 119 is compared with a reference voltage generated on the chip. The comparison is done in comparator section 108, and when the voltage reaches a preset comparison voltage, the comparator section 108 sends a signal on line 118 down an optional pulse sharpening and delay section 112. When the pulse reaches the end of the pulse sharpening and delay section 112, a local clock signal is sent out on line 101, and a pulse is sent back on line 114 to transistor 110 which discharges capacitor section 106 so that the voltage across capacitor section 106 falls to a low value. Then the voltage starts to build up until it again reaches the preset comparison voltage. The time between two discharges of the capacitor section 106 is the time between two ticks of the local clock. A series of narrow spikes is sent out from the oscillator section on line 101 representing ticks of the local clock.

A phase reset signal is brought in to the sharpen and delay module on line 116 when, for example, the tag detects a rising or falling edge of the digital signal on line 62. The sharpen and delay module 112 then sends a pulse on line 114 to the transistor 110 to both discharge the capacitor section 106 and reset the phase of the local clock signal on line 101. The phase reset signal also serves to clear the sharpen and delay line in the sharpen and delay module 112. A signal is also sent on line 117 to clear the voltage comparator section 108 when the phase reset signal passes through the sharpen and delay line.

One or more of the sections 104, 106, and 108 are digitally controlled by signals from the calibrate module 300 sent out on line 302. These calibrate module outputs are set using base station output modulation patterns. Thus, the tag oscillator frequency is controlled by the signals from the base station to be one of a plurality of possible discrete frequencies. Circuits for analog control of the tag oscillator are anticipated by the inventors, but the digital control is preferred since the circuits required are more stable and require less current.

The most preferred embodiment of the oscillator section 100 uses an innovative, very low current source section 104 with the value of the current set by the calibrate module using voltages brought to the current source section 104 on connection 302. FIG. 5a shows a circuit diagram of the most preferred circuit of blocks 104, 106, and 108 which may produce a clock signal running at approximately 8 times the RF modulation frequency f_1 .

Transistors M2-M6 are each capable of sourcing a defined current on to capacitor C67, depending on whether control transistor switches M8-M12 are on or off. Voltages at nodes 120, 121, 122, 123, and 124 which are set by voltages carried over connection 302, control transistors M8-M12.

Transistor M1 supplies capacitor C67 with a small current from the tag power supply at voltage VDD. This small current is independent of the calibrate module control on

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line 302. When nodes 120-124 are set high by voltages supplied on connection 302 from the calibrate module 300, transistors M8-M12 do not conduct current. The tag oscillator runs at a relatively low frequency, (since at low current the capacitor C67 charges slowly to the comparison voltage) and the digital clock signal produced on line 102 is used to check whether an unmodulated RF signal is being sent from the base station for a sufficiently long time in the first step of the method of the invention called the preamble detect step. As will be shown later, the system then may calibrate the oscillator by setting voltages on nodes 120-124. When the tag oscillator is running in the slowest mode, the average current draw is only 100 nA, as the current is drawn through most of the devices shown in FIG. 5a and FIG. 5b only for a very short time when there is a transition and a clock pulse is produced. As one or more of the control transistors M8-M12 are turned on, the oscillator runs faster, and the feedback from the calibrate module is used to set the nodes 120-124 so that the oscillation frequency is adjusted with respect to the base station RF modulation frequency.

Transistors M1-M6 are p-FETs controlled by the voltage VPMR, and the current through each transistor mirrors the current through a standard p-FET elsewhere on the chip. In the operating regime of the circuit of FIG. 5, the relative current through each transistor M1-M6 is defined by the geometry of the transistors, as is well known to one skilled in the art of analog integrated circuit design. The currents through transistors M1-M6 are in the ratio 2:1:2:4:8:16 respectively. On the chip, transistors M1-M6 are implemented as multiple devices of the same size. Thus, the transistor with weight 16 is actually 16 identical transistors connected in parallel. (The transistors have dimensions $w=5\mu\text{x}l=10\mu$ in a preferred implementation.) The current from current source 104 can thus be set at approximately every integral multiple between 2 and 33 of a base current of approximately 35 nA by appropriate adjustment of voltages on nodes 120-124. There are thus 32 different tag oscillator frequencies that can be generated by the tag oscillator 100.

It is clear to one of ordinary skill in the art that more or fewer transistors such as M2-M6 could be used to set more or fewer values of the tag oscillator frequency. It is also clear that the settable frequencies are not necessarily equally distributed through the desired frequency region. It is well within the scope of the invention to have non-integral ratios for the currents from transistors M1-M6 to provide finer control near the most desired frequency, and yet allow wider excursions from the mean of the allowed frequencies. It is also well within the scope of the invention to reverse the p and n channel circuits shown in the figures with equivalent n and p channel circuits. The circuit shown is preferable, however, in that the current supplies are somewhat more stable in an environment where VDD may shift and where the ground is more stable.

An alternative preferred embodiment of the oscillator section 100 uses a capacitor section 106 with a value of the capacitance set by the calibrate module using voltages on connection 302. This embodiment is shown in the circuit diagram of FIG. 6 for the capacitor section 106. In this case, the current source section 104 would preferably comprise one or two p-fet transistors. The digitally controlled capacitor section 106 shown in FIG. 6 runs at the fastest rate when all capacitors C_1-C_5 are switched off from receiving current from the current source section 104, and the smallest capacitor C_6 is used. In this case, the variations in manufacture of the limited current supply transistors and the capacitance C_6 would lead to unwanted variations in the maximum tag

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oscillation frequency. This disadvantage outweighs the advantage that the oscillator draws approximately the same low constant current at all times (although the current used during the transitions may vary greatly with frequency).

An alternative preferred embodiment of the oscillator section 100 uses a comparison voltage in section 108 with a value of the comparison voltage set by the calibrate module using voltages on connection 302. This embodiment is shown in the circuit diagram of FIG. 7 for the voltage comparator section 108. In this case, the current source section 104 would preferably be one or two p-fet transistors, and the capacitance section 106 would be a preferably comprise a single capacitor. This circuit works by providing a controllable way to unbalance the current sources which supply the differential pair in the first stage of the comparator. Unbalancing the current sources serves to move the comparator trip point.

The digitally controlled current source section 104 sketched in the circuit of FIG. 5a is preferred over the digitally controlled capacitance section 106 or the digitally controlled voltage comparator section 108 sketched in FIGS. 6 and 7 respectively. The current is extremely low when the oscillator frequency is low, and the stability and predictability of the oscillation frequency is not as important as when the frequency is raised for the purposes of tag communication. At the higher tag oscillator frequencies, the current draw is higher, and as a result the frequency is much more stable and predictable and is less affected by manufacturing and tag environmental variations.

Transistor M70 and capacitor C69 are optionally included in the oscillator section to slightly slow the oscillator after the oscillation frequency has been set. Thus, the frequency could be set so that there are approximately 9 counts of the clock in every base station modulation frequency interval. M70 can then be turned on, which will guarantee that there are less than 9 counts per interval.

A preferred comparator section 108 is also shown in FIG. 5a. This voltage comparison circuit is well known to one skilled in the art. For example, see page 333 of Allen and Holberg—CMOS Analog Circuit Design (1987).

The optional sharpen and delay module 112 circuit is shown in FIG. 5b. While the signal on line 118 could be used as a clock signal for the tag electronics and could be used to discharge capacitor section 106 through transistor 110 if it were connected to line 114, the slow rise time of signal on line 118 would waste current in the digital gate using it as input. Furthermore, the oscillator output spike might be too narrow.

The series of resettable inverter circuits in the sharpen and delay module 112 shown in FIG. 5b serve to delay and sharpen the final pulse applied to line 102. The delay allows us to perform computations on both rising and falling edges of the oscillator output with adequate intervening setup and hold time. The sharpen and delay circuit is also more broadly required to ensure a wide enough clock pulse width for use by the digital electronics on the chip. The sharpen and delay circuit is innovative in that it works at low current due to the current limited early gain stages. The circuit is also innovative in that it is resettable, in that the delay line is cleared of data when an oscillator reset is requested. When the circuit without resettable was tried, it was not reliable.

FIG. 8 shows a flow chart 800 of a method of implementing and using the apparatus of the invention. In step 805, the base station sends out a steady, unmodulated "Preamble Detect" signal. In step 810 the base station oscillator section is running with the appropriate voltages set on nodes

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120–124 so the tag oscillator runs at the slowest frequency allowable. The tag counter is reset on the rising edge of the base station steady, unmodulated signal, and the tag counter counts the clock pulses on line 102. The tag counts the pulses until the next edge of the base station signal and compares the tag counter count to a certain preset number, for example, 8. If the tag counter count is greater than 8, the tag decides that the base station is sending a preamble detect signal, and readies itself for the next step. If the number of counts is less than 8 the tag resets the tag counter and begins again to wait for a long enough time t of steady, unmodulated RF. The waiting period prevents the oscillator from calibrating in the middle of a data transmission, as might occur if a tag enters the base station field during base station communication with another tag.

After the base station has sent a steady RF signal for the required length of time in step 805, the base station in step 815 starts to send a steadily modulated signal where the RF is turned on and off at a frequency f_1 . At the rising edge of the first modulated pulse, the tag starts the calibration procedure of step 820, and for the next N pulses (where N is an integer) of the steadily modulated RF from the base station, the tag sets the calibration of the tag oscillator so that the tag oscillator frequency is set approximately to a certain multiple of the base station modulation frequency f_1 . When the base station has sent a sufficient number of pulses in step 815 that the tag has had time to complete step 820, the base station sends a particular modulation pattern called a "Start Delimiter Code" in step 825. The start delimiter code optionally contains pulses that are "too long" in that the RF field is "on" for three times as long as would be the case when the base station were sending a steadily modulated RF signal with modulation frequency f_1 . This "long pulse" technology is innovative in the field of RF tags. The tag receives the start delimiter code in step 830, using the start delimiter code to check that the tag oscillator frequency is indeed set correctly and that the tag is decoding valid base station data. Further, the receipt of the start delimiter code ensures that the tag matches the base station's place in the data stream. If the start delimiter code is not received correctly, the tag returns to step 810. The tag proceeds to the next step 840 of receiving the command sent by the base station. Meanwhile, the base station now transmits command data in step 835. Such data could be instructions to the tag to write data to the tag memory, to read data from the tag memory and transmit the data to the base station, to set some tag state indicator, or for the tag to perform some other tag function which the particular tag may be able to perform. The tag receives the command data in step 840, and decides in step 850 on the basis of the command data what to do. If the command data is garbled, the tag cannot understand what to do, and returns to step 810 to wait for another try. If the tag does understand the command data, the tag may write data to the tag memory in step 870 or transmit data to the base station in step 860, as examples, and then the tag returns to step 810 to await further orders. During the writing of data to the tag memory 870 or transmitting data to the base station step 860, the base station transmits full power in a steady unmodulated stream of RF power in order to supply power throughout the relatively slow E²-PROM write operation. (If faster memory elements such as ferroelectric random access memory (FRAM) memory elements are used, the tag may write the memory at the same time as the data is received.) The base station receives any data sent from the tag in step 855 which takes place simultaneously with step 845, and then takes further action as appropriate.

A flow chart 900 of the method of calibrating the tag oscillator is shown in FIG. 9. The tag resets the tag oscillator

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so that the tag oscillator frequency is the lowest possible frequency in step 910. In the example given by FIG. 5a and FIG. 5b, all nodes 120–124 would be set high so that only low current charges capacitor section 106. The most significant bit is then reset to 0 in step 920. The local counter 200 is reset to zero on the rising edge of the steadily modulated RF field sent out by the base station in step 815 of FIG. 8. (It is clear to one skilled in the art that falling edges could also be used, or any other regular transitions.) The local counter then counts pulses on line 102 in step 940 until the next rising edge of the steadily modulated RF field sent out from the base station. If the count value is greater than 8 (ie 9 or greater), the decision step 950 sends the system to step 960, where the last bit which was reset to zero is set back to one. (The oscillator is running too fast, and has to be slowed down. Because the control devices are p-FETs in the embodiment described, a logic level 1 is used to turn them off.). If the count is less than 9, the oscillator is running slow, and the system skips from step 950 to 970 to reset the next significant bit to zero. If all the control bits have not been reset, the system then decides at step 980 to return to step 930 to measure again whether the oscillator is running fast or slow compared to the base station modulation frequency, and the process is repeated in order from the most significant bit to the least significant bit until all nodes 120–124 in FIG. 5a are set correctly so that the tag oscillator frequency is just under 9 times the base station modulation frequency. Of course, it is clear to one skilled in the art that the count value could be more or less than 8 for the tag to calibrate the tag oscillator with respect to the base station modulation frequency. When all the bits have been reset (and possibly set again to 1), the system moves to step 990 and optionally reduces the tag oscillator frequency so that it is surely less than 9 times the base station modulation frequency.

Throughout the rest of the data stream, the settings on nodes 120–124 remain fixed. However, the phase reset signal 116 continues to be generated to maintain synchronization during the base station to tag data transmission.

Note that the phase reset signal 116 is not generated while the tag is writing data to the tag memory or while the tag is transmitting data to the base station. During these operations, the base station transmits unmodulated RF power, and the tag clock section 40 is free running at the calibrated frequency which is determined by the settings on nodes 120–124.

It will be apparent to one skilled in the art that circuits equivalent to those disclosed herein may be used for the purposes stated herein. In particular, the equivalent n-FET and p-FET circuits are anticipated by the inventors.

We claim:

1. A passive radio frequency (RF) transponder (tag) for receiving an RF signal from a base station, comprising;
 - a tag antenna for receiving the RF signal from the base station the RF signal having a carrier frequency;
 - a tag rectification power supply connected to the tag antenna;
 - a tag logic section and a tag memory section the tag logic section and the tag memory section receiving power only from the tag antenna through the tag rectification power supply;
 - a receiver section connected to the tag antenna; and
 - a tag oscillator connected to the receiver section, the tag oscillator having a plurality of possible discrete frequencies of oscillation, the tag oscillator having a tag oscillation frequency much less than the carrier frequency, the tag oscillator frequency used to deter-

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mine a tag modulation frequency of an RF signal backscattered from the tag antenna, the tag oscillation frequency determined by the RF signal sent from the base station.

2. The RF tag of claim 1, where the RF signal is modulated at a modulation frequency f_1 , and the frequency of oscillation of the tag oscillator is determined by f_1 .

3. The RF tag of claim 2, where the RF signal is amplitude modulated at a modulation frequency f_1 .

4. The RF tag of claim 2, where the RF signal is frequency modulated at a modulation frequency f_1 .

5. The RF tag of claim 2, where the RF signal is phase modulated at a modulation frequency f_1 .

6. The RF tag of claim 1, wherein the tag oscillator further comprises;

a current source section;

a capacitor section, the capacitor section charged from the current source section;

a voltage comparator section, the voltage comparator section comparing the voltage across the capacitor section to a preset comparison voltage; and

a switch, the switch discharging the capacitor section when the voltage across the capacitor section reaches the preset comparison voltage.

7. The RF tag of claim 6, where the current source section comprises a plurality of defined current sources, at least one of the plurality of defined current sources being controlled to charge the capacitor section in response to the RF signal sent from the base station.

8. The RF tag of claim 7, where at least one of the defined current sources is a defined current transistor in series with a transistor switch.

9. The RF tag of claim 6, where the capacitor section source comprises a plurality of capacitances connected in parallel, at least one of the plurality of capacitances being controlled to receive current or not to receive current from the current source section in response to the RF signal sent from the base station.

10. The RF tag of claim 6, where the comparator section source further comprises a plurality of defined current sources for delivering current to a voltage comparison circuit, at least one of the plurality of defined current sources being controlled to deliver current in response to the RF signal sent from the base station.

11. The RF tag of claim 1, where the tag oscillator uses less than 500 microamperes of current.

12. The RF tag of claim 11, where the tag oscillator uses less than 1 microampere of current.

13. A method of setting a tag oscillation frequency of a tag oscillator of a passive RF tag comprising;

a) receiving an RF signal from a base station, and;

b) adjusting the tag oscillation frequency in response to the RF signal from the base station, wherein the tag oscillation frequency is much less than a carrier frequency of the RF signal, and wherein the tag oscillation frequency is used to determine a tag modulation frequency of an RF signal backscattered from the tag.

14. The method of setting an oscillation frequency of claim 13, where the RF signal is modulated at a modulation frequency f_1 and the oscillation frequency is set as a function of f_1 .

15. The method of claim 14, where the RF signal is amplitude modulated at a modulation frequency f_1 .

16. The method of claim 14, where the RF signal is frequency modulated at a modulation frequency f_1 .

17. The method of claim 14, where the RF signal is phase modulated at a modulation frequency f_1 .

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18. The method claim 14, where the tag counts the number of tag oscillator pulses in one period of the base station modulation frequency, and adjusts tag oscillator frequency so that the number is approximately equal to a preset number.

19. A method of setting an oscillation frequency of a tag oscillator of a passive RF tag, where the tag adjusts the oscillator frequency according to the following steps;

- a) setting the tag oscillator so that the tag oscillation frequency is the lowest possible frequency by setting all control bits equal to one;
- b) resetting the most significant bit equal to zero;
- c) resetting a local counter of tag oscillator pulses on a rising edge of the steadily modulated RF field sent out by the base station;
- d) counting pulses of the tag oscillator until the next rising edge of the steadily modulated RE field sent out from the base station;
- e) if the count value is greater than a preset number, resetting the local counter, setting the last bit reset to one, resetting the next significant bit to zero, and returning to step (c);
- f) if the count value is less than the preset number, resetting the local counter, resetting the next significant bit to zero, and returning to step (c); and
- g) continuing until all control bits have been set or reset and the count value is approximately equal to the preset number.

20. The method claim 19, where the tag further adjusts the oscillator frequency in the additional step;

- h) slowing the tag oscillator so that the count value is definitely less than the preset number, and definitely more than the preset number minus one.

21. The method claim 19, where the tag further adjusts the tag oscillator in the additional step of; resetting the tag oscillator phase on the rising edge of the steadily modulated RF field sent out by the base station.

22. A system for sending and receiving modulated RF signals, comprising;

- a base station for sending modulated RF signals, the RF signals having a carrier frequency; and
- at least one passive RF tag for receiving the RF signals, the RF tag comprising a tag antenna for receiving the

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RF signal from the base station, a tag receiver section connected to the tag antenna; and a tag oscillator connected to the tag receiver section, the tag oscillator having a tag oscillation frequency much less than the carrier frequency, the tag oscillation frequency used to determine the a modulation frequency of an RF signal backscattered from the tag antenna, the tag oscillator frequency determined by the Rf signals sent by the base station.

23. The system of claim 22, where the base station sends RF signals modulated at a modulation frequency f_1 , and the frequency of oscillation of the tag oscillator is determined by the modulation frequency f_1 .

24. The system of claim 23, where the RF signal is amplitude modulated at a modulation frequency f_1 .

25. The system of claim 23, where the RF signal is frequency modulated at a modulation frequency f_1 .

26. The system of claim 23, where the RF signal is phase modulated at a modulation frequency f_1 .

27. The system of claim 22, where the base station further comprises a computer for receiving and sending data from and to the tag.

28. A passive radio frequency (RF) transponder (tag) for receiving an RF signal from a base station, comprising;

- a tag antenna for receiving the RF signal from the base station, the RF signal having a carrier frequency;
- a receiver section connected to the tag antenna;
- a tag rectification power supply connected to the tag antenna;
- a tag logic section and a tag memory section, the tag logic section and the tag memory section receiving power only from the tag antenna through the tag rectification power supply; and
- a tag oscillator connected to the receiver section, the tag oscillator having a tag oscillation frequency much less than the carrier frequency, the tag oscillation frequency used to determine a tag modulation frequency of an RF signal backscattered from the tag antenna, the tag oscillation frequency determined by the RF signal sent from the base station.

* * * * *

EXHIBIT B

US005528222A

United States Patent [19]

Moskowitz et al.

[11] **Patent Number:** 5,528,222[45] **Date of Patent:** Jun. 18, 1996[54] **RADIO FREQUENCY CIRCUIT AND MEMORY IN THIN FLEXIBLE PACKAGE**[75] **Inventors:** Paul A. Moskowitz, Yorktown Heights; Michael J. Brady, Brewster; Paul W. Coteus, Yorktown Heights, all of N.Y.[73] **Assignee:** International Business Machines Corporation, Armonk, N.Y.[21] **Appl. No.:** 303,977[22] **Filed:** Sep. 9, 1994[51] **Int. Cl.⁶** H04Q 1/02[52] **U.S. Cl.** 340/572; 29/825; 29/829; 29/836; 340/825.3; 340/825.34; 340/825.54[58] **Field of Search** 340/572, 825.34, 340/825.3, 825.54; 29/836, 829, 825[56] **References Cited****U.S. PATENT DOCUMENTS**

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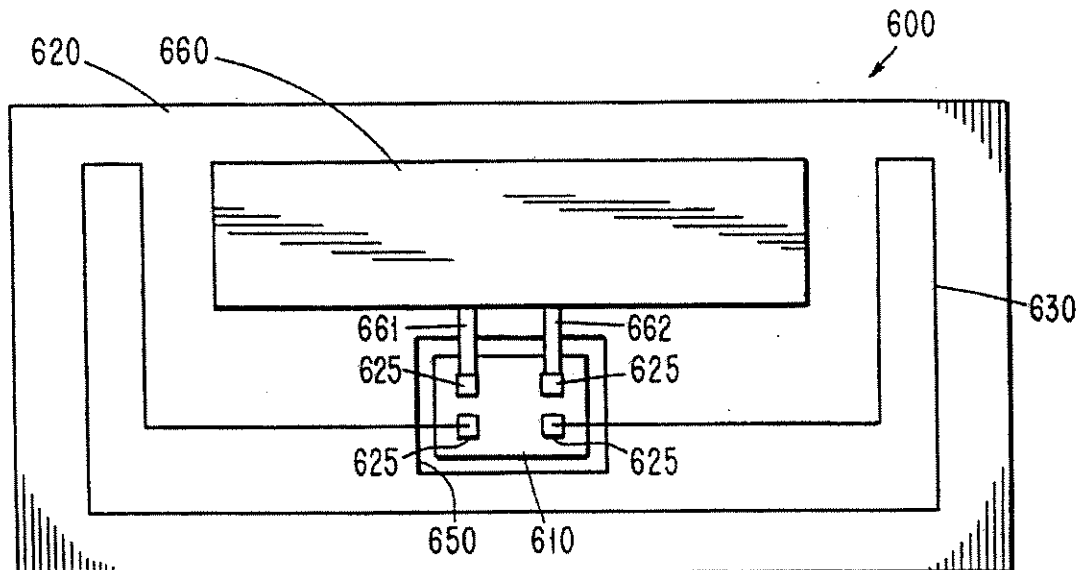
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Primary Examiner—Glen Swann*Attorney, Agent, or Firm*—Louis J. Percello[57] **ABSTRACT**

A novel thin and flexible radio frequency (RF) tag has a semiconductor circuit with logic, memory, and a radio frequency circuits, connected to an antenna with all interconnections placed on a single plane of wiring without crossovers. The elements of the package (substrate, antenna, and laminated covers) are flexible. The elements of the package are all thin. The tag is thin and flexible, enabling a unique range of applications including: RF ID tagging of credit cards, passports, admission tickets, and postage stamps.

29 Claims, 10 Drawing Sheets

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FIG. 1A
PRIOR ART

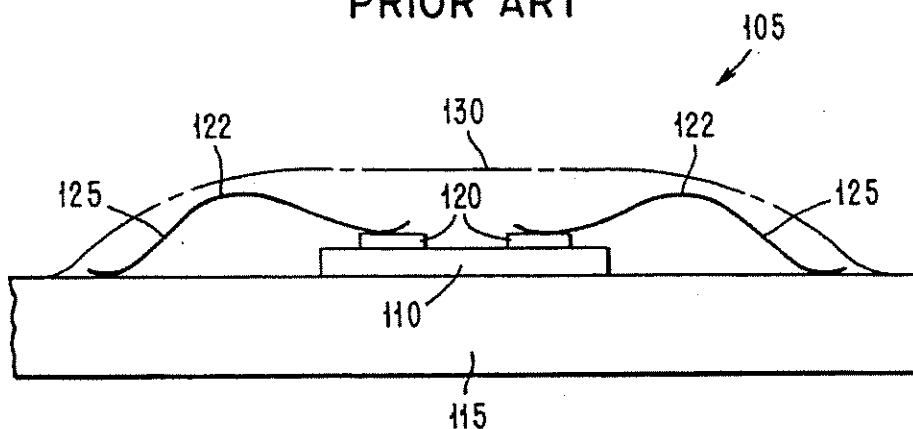
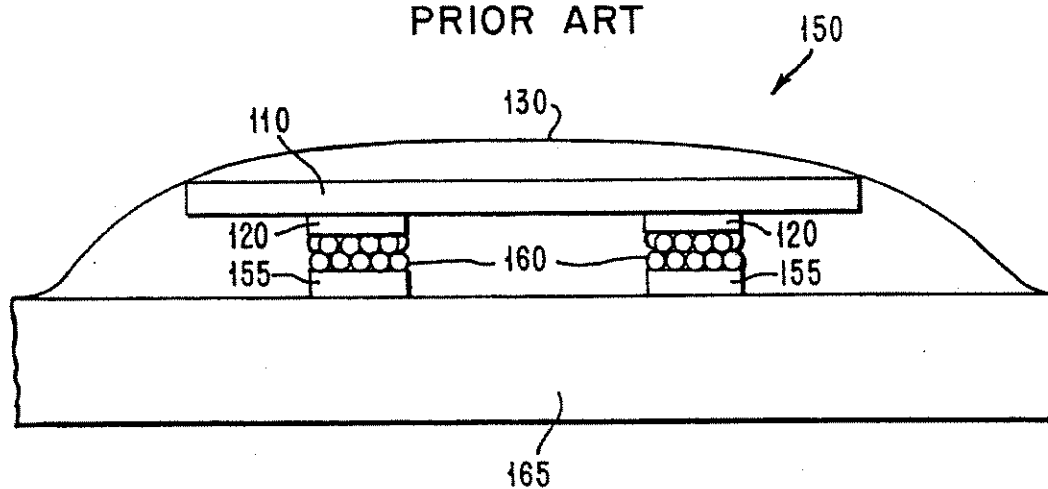


FIG. 1B
PRIOR ART



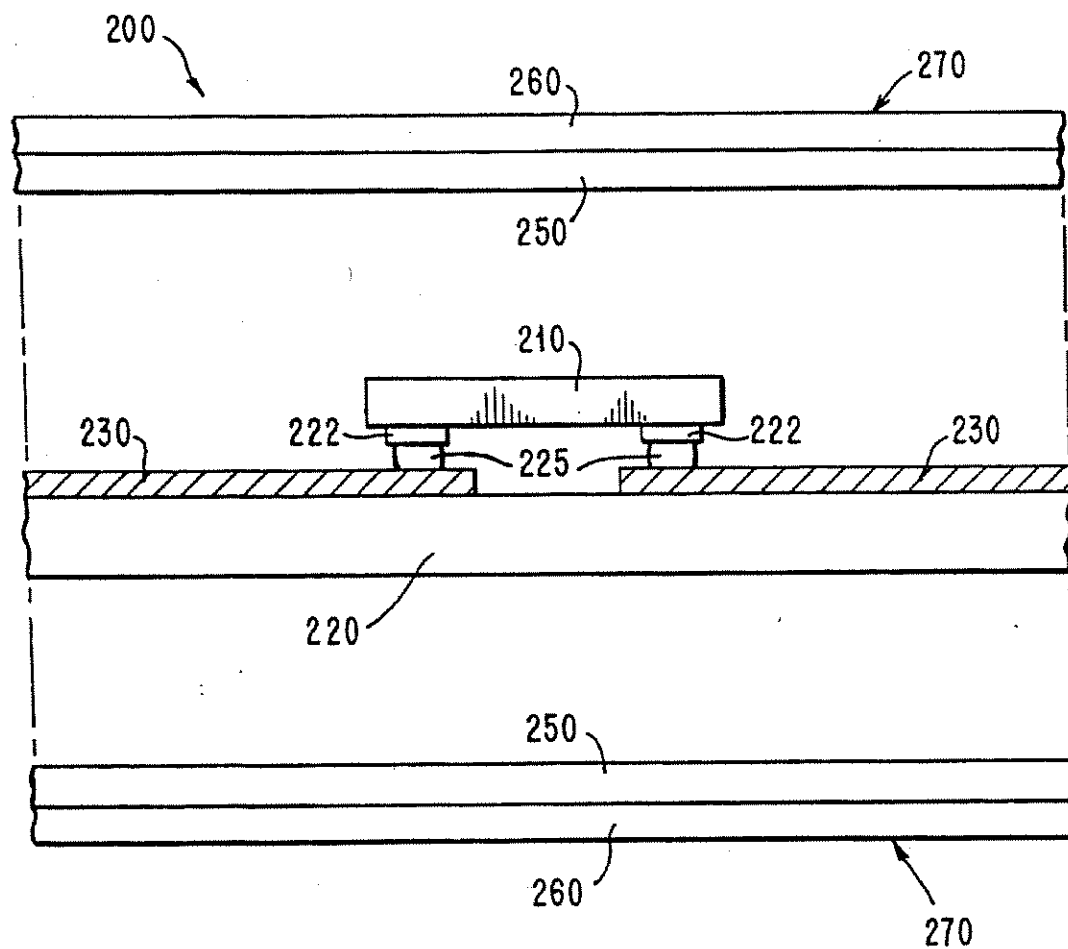
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FIG. 2



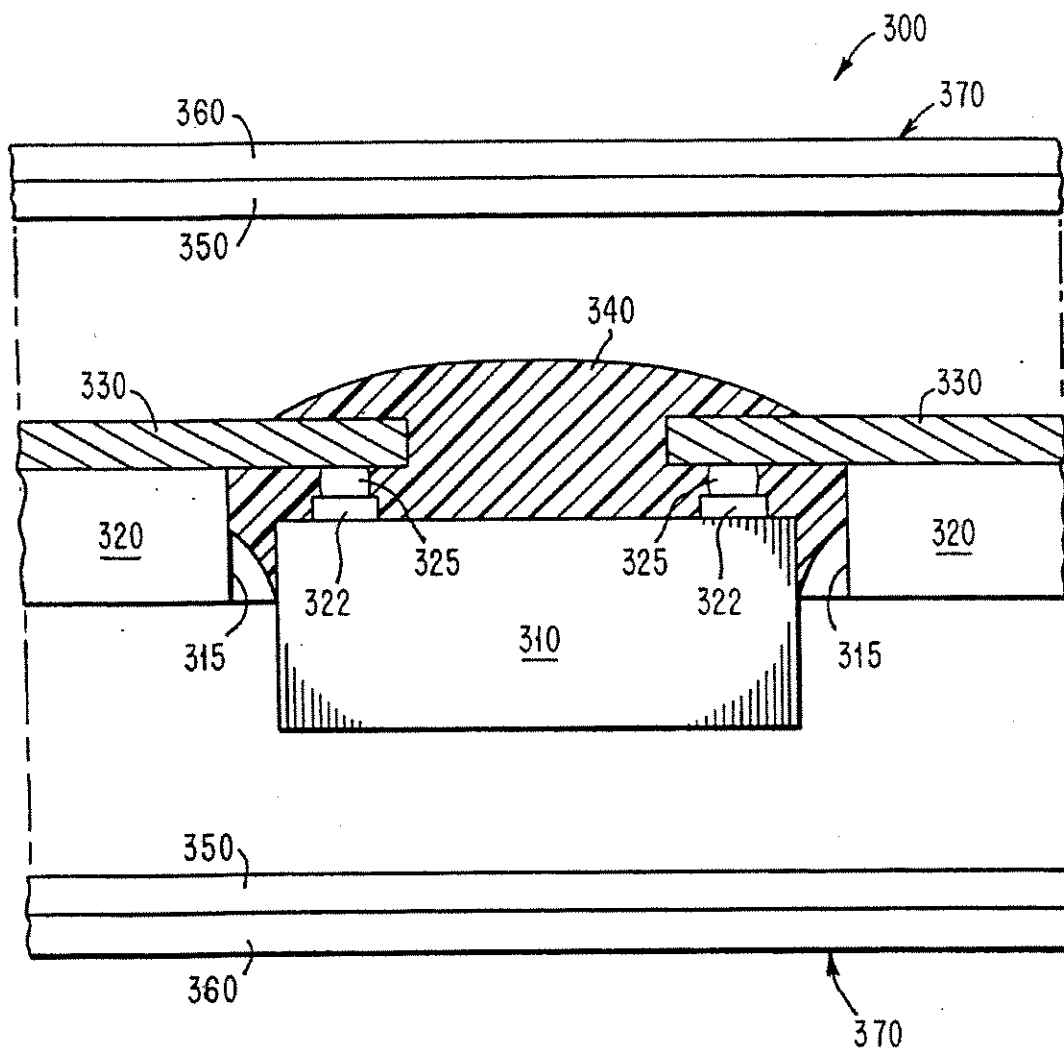
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FIG. 3



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FIG. 4

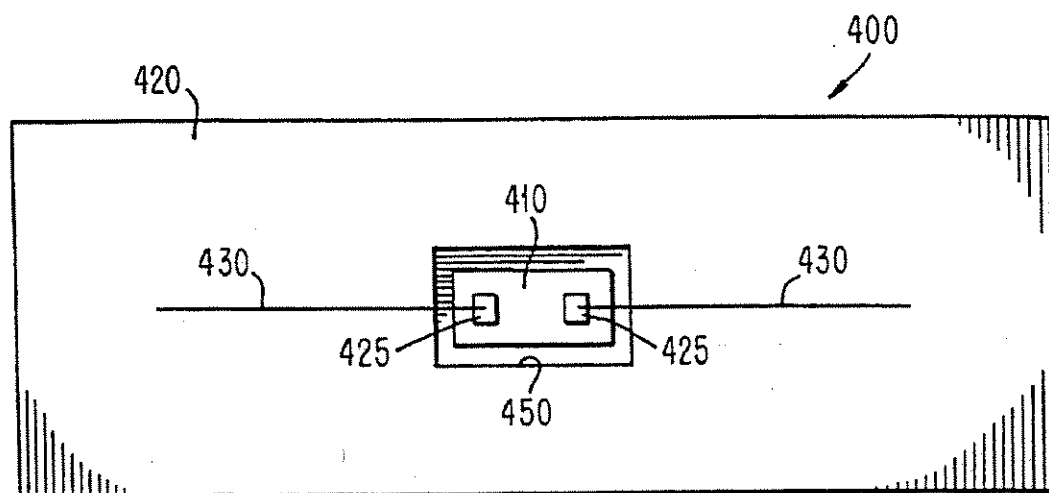
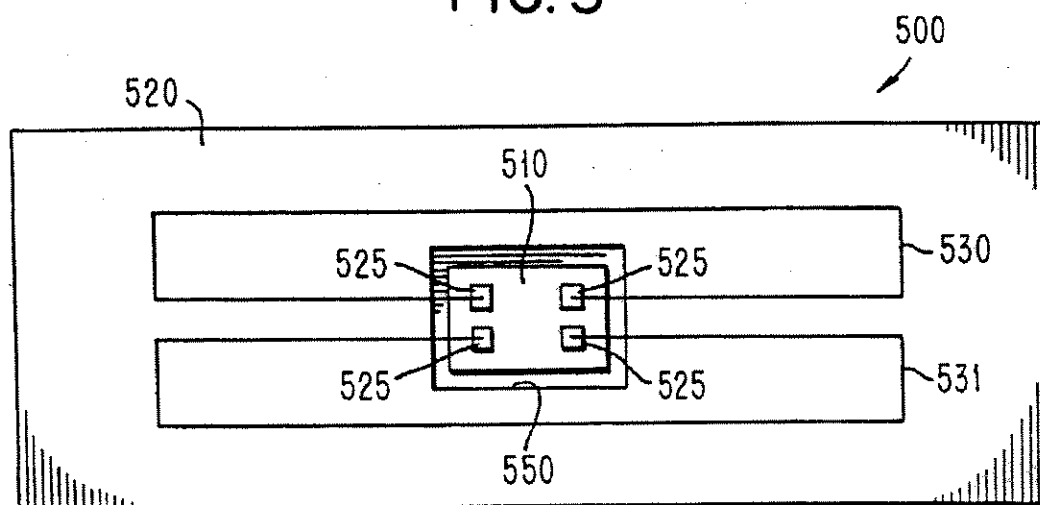


FIG. 5



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FIG. 6

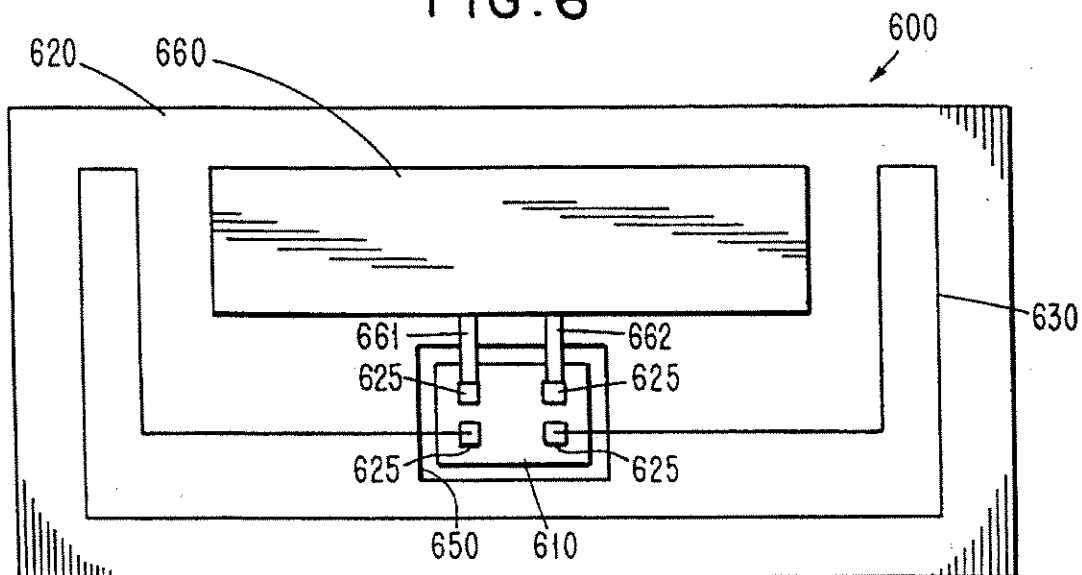
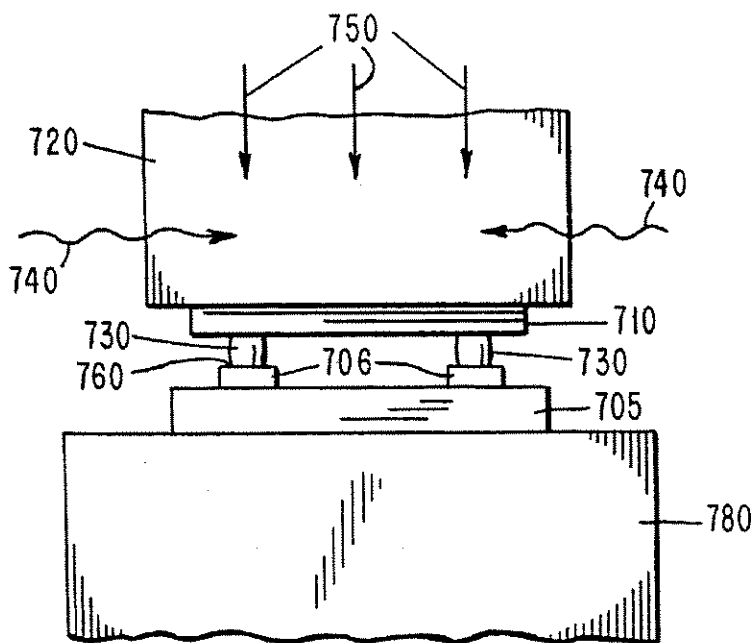


FIG. 7A PRIOR ART



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FIG. 7B
PRIOR ART

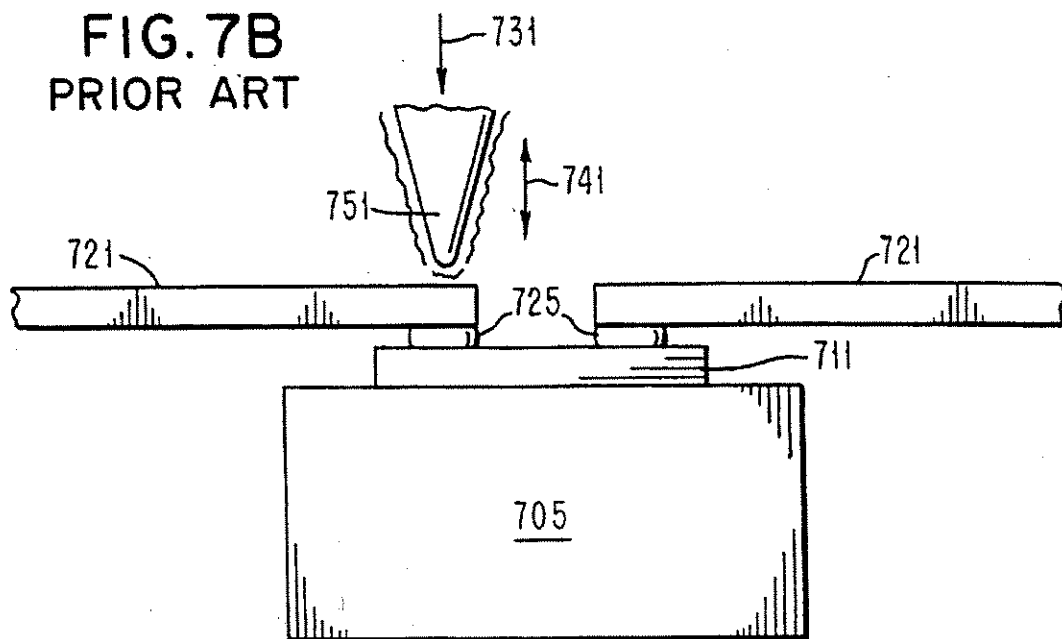
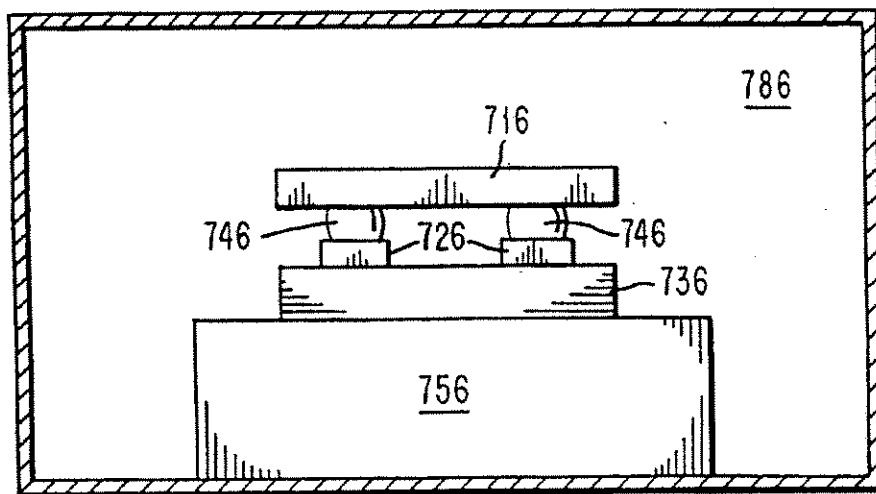


FIG. 7C
PRIOR ART



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FIG. 7D
PRIOR ART

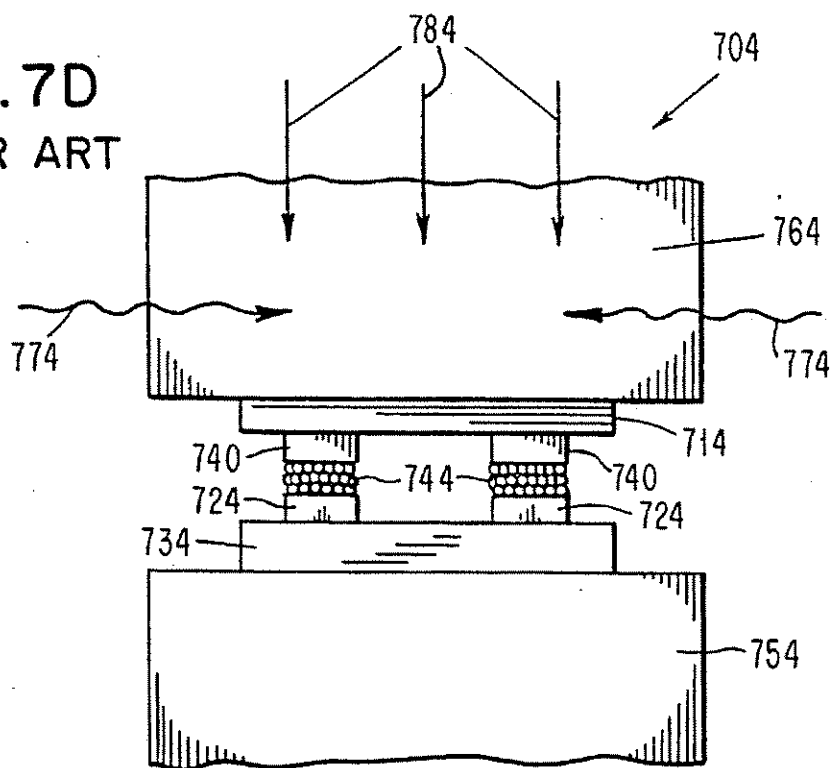
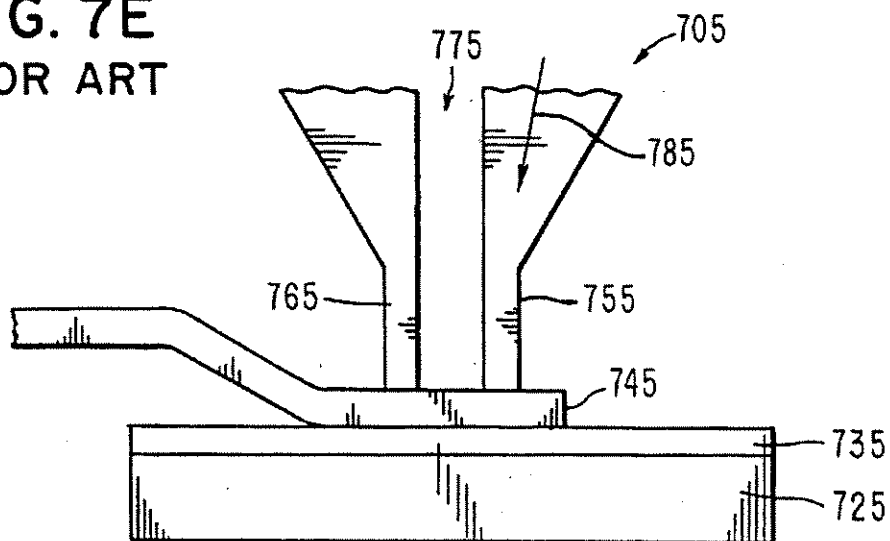


FIG. 7E
PRIOR ART



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FIG. 8

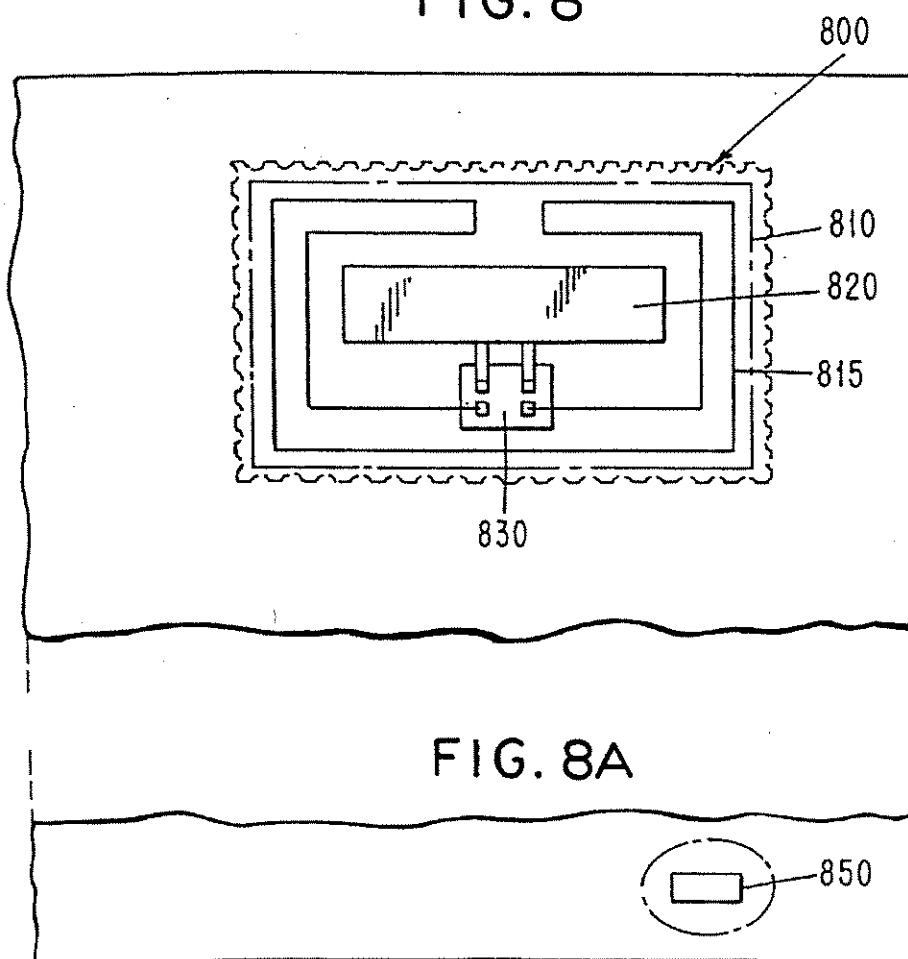


FIG. 8A

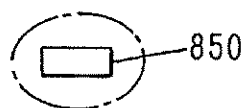
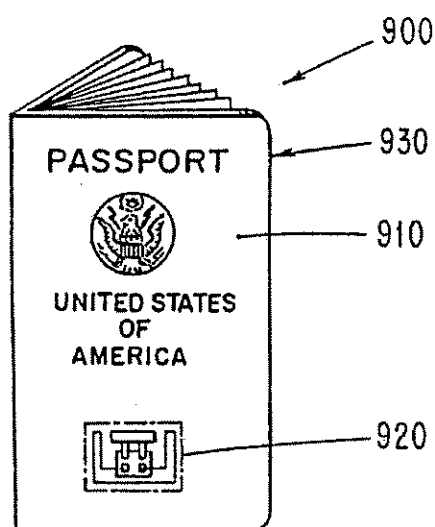


FIG. 9



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FIG. 10

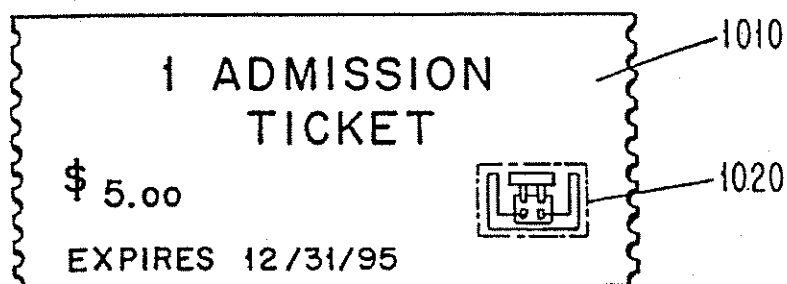
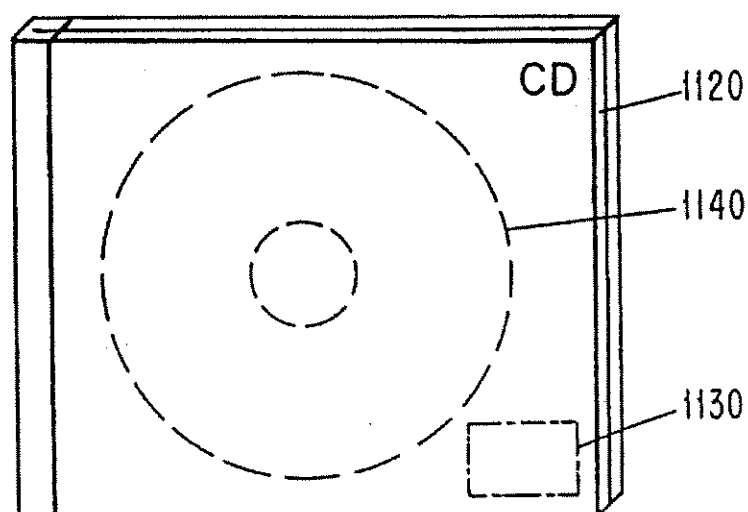


FIG. 11



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FIG. 12

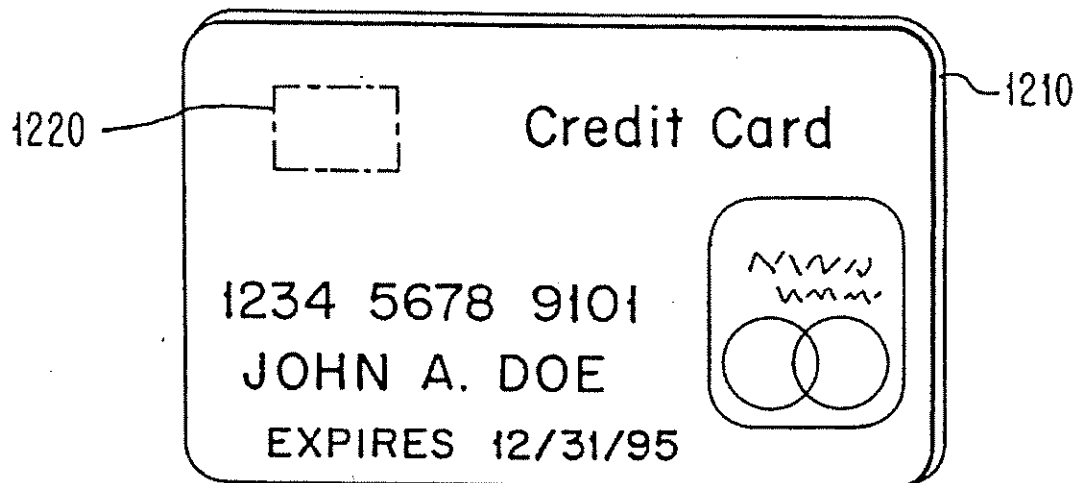
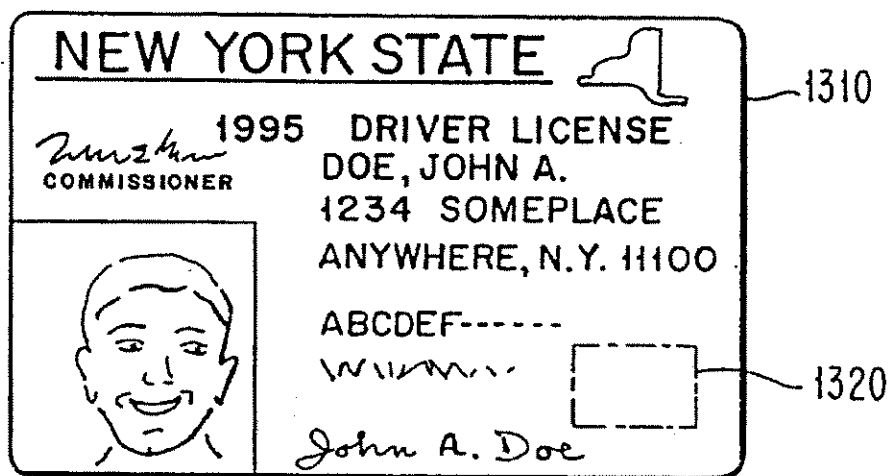


FIG. 13



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RADIO FREQUENCY CIRCUIT AND MEMORY IN THIN FLEXIBLE PACKAGE

FIELD OF THE INVENTION

This invention relates to a radio frequency circuit and memory in a thin flexible package. More specifically, the invention relates to a thin flexible radio frequency circuit used as a radio frequency tag.

BACKGROUND OF THE INVENTION

Radio Frequency Identification (RF ID) is just one of many identification technologies for identifying objects. The heart of the RF ID system lies in an information carrying tag. The tag functions in response to a coded RF signal received from a base station. Typically, the tag reflects the incident RF carrier back to the base station. Information is transferred as the reflected signal is modulated by the tag according to its programmed information protocol.

The tag consists of a semiconductor chip having RF circuits, logic, and memory. The tag also has an antenna, often a collection of discrete components, capacitors and diodes, for example, a battery in the case of active tags, a substrate for mounting the components, interconnections between components, and a means of physical enclosure. One variety of tag, passive tags, has no battery. They derive their energy from the RF signal used to interrogate the tag. In general, RF ID tags are manufactured by mounting the individual elements to a circuit card. This is done by using either short wire bond connections or soldered connections between the board and the circuit elements: chip, capacitors, diodes, antenna. The circuit card may be of epoxy-fiberglass composition or ceramic. The antennas are generally loops of wire soldered to the circuit card or consist of metal etched or plated on a circuit card. The whole assembly may be enclosed in a plastic box or molded into a three dimensional plastic package.

While the application of RF ID technology is not as widespread as other ID technologies, bar code for example, RF ID is on its way to becoming a pervasive technology in some areas, notably vehicle identification.

Growth in RF ID has been inhibited by the high cost of tags, the bulkiness of most of the tags, and problems of tag sensitivity and range. A typical tag costs in the \$5 to \$10 range.

Companies have focused on niche applications. Some prior art is used to identify railway boxcars. These tags tend to be quite large and are made of discrete components on circuit boards mounted in solid, non-flexible casings. RF tags are now used in the automatic toll industry, e.g. on thruway and bridge tolls. RF tags are being tested for uses as contactless fare cards for buses. Employee identification badges and security badges have been produced. Animal identification tags are also commercially available as are RF ID systems for tracking components in manufacturing processes.

Tags exist that have the length and width of a standard credit card. However, these cards typically are over 2.5 mm thick and have a non-flexible casing. Tags also exist that have a credit card size length and width but with bumps where circuit is placed that causes them to be too thick to fit in card reader machinery.

While some electronic article surveillance (EAS), e.g. anti-theft devices, are thin (0.3 mm) they typically contain limited amounts, (i.e., only one bit) of information. Some of

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these devices can be turned off once but cannot be reactivated.

FIG. 1A shows one prior art structure of a radio frequency tag 105. The tag 105 has a chip 110 mounted on a substrate 115. The chip 110 has contacts 120 that are connected to circuitry on the substrate 115 by wire bonds 125. An encapsulation material 130 covers the chip for environmental protection. The thickness of this tag 105 is determined by the combined thicknesses of the chip components. Typically, substrates in these tags are at least 10 mils, 0.25 mm, in thickness, the chip 110 along with the high loop 122 of the bond vary from 20 to 40 mils, 0.5 to 1 mm, in thickness and the encapsulation 130 is about 10 mils, 0.25 mm in thickness. As a result, tags 105 of this structure vary from a minimum of 40 to 60 mils, 1 to 1.5 mm, in thickness. This structure is too thick for many potential tag applications.

FIG. 1B shows another prior art structure 150 showing a chip 110 with the chip contacts 120 connected to circuitry contacts 155 with conducting adhesive 160. The substrate 165 of this structure 150 is typically made as a FR4/printed circuit (thickness 40 to 60 mils, 1 to 1.5 mm) or flexible substrate (10 mils, 0.25 mm). The chip 110 and adhesive 160 add another 20 to 40 mils, 0.5 to 1 mm, to the thickness and the encapsulation 130 adds still another 10 to 20, 0.25 to 0.5 mm mils in structure 150 thickness. This structure therefore can vary in thickness from 80 to 130 mils, 2 to 3.5 mm, making it thicker than the structure in FIG. 1A.

Other thick structures are known in the art. These include quad flat pak (QFP) and/or small outline pak (SOP) as components. Structures made with these components are at least 1 mm thick and usually 2 to 3 mm thick.

PROBLEMS WITH THE PRIOR ART

Prior art teaches that there is a long felt need to manufacture thin RF ID tags on flexible substrates. However, while the goal of a thin flexible tag is desired, the prior art has failed to reach the goal. One prior art reference discloses a tag that is 1.5 to 2.0 mm thick. This tag thickness limits the applications of this tag. For example, it is far thicker than the International Organization for Standardization (ISO) standard credit card thickness of 0.76 mm and therefore could not be used in a credit card to be inserted into a credit card reader.

The prior art has failed to produce a thin tag because: care is not been taken to make each of the elements thin; elements are stacked one upon the next; and the antenna and connecting conductors require more than one plane of electrical wiring, i.e. the designs use cross-overs for completing interconnections. As elements are stacked and layers are added the package grows thicker and flexibility is lost.

Another prior art reference discloses a package with a total thickness of 0.8 mm. This is still greater than the ISO standard credit card thickness of 0.76 mm. Furthermore, while thin elements are disclosed, no care is taken to use flexible materials throughout. The components are mounted on a hard circuit card and encapsulated in plastic. (Hard means can not be torn easily by hand.) The result is a rigid package. The prior art has not shown the use of thin flexible laminate covering materials for the packages. The results are that the packages are thick, and inflexible.

OBJECTS OF THE INVENTION

An object of this invention is an improved thin radio frequency tagging apparatus.

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An object of the invention is a flexible radio frequency tag apparatus with a thin flexible protective lamination.

An object of the invention is a flexible radio frequency tag apparatus that may fit within the thickness limit of an ISO standard credit card, a passport cover, a postage stamp, an anti-theft device, or an admission ticket.

SUMMARY OF THE INVENTION

The present invention is a novel radio frequency (RF) tag that comprises a semiconductor circuit that has logic, memory, and radio frequency circuits. The semiconductor is mounted on a substrate and is capable of receiving a RF signal through an antenna that is electrically connected to the semiconductor through connections on the semiconductor. The present invention is a novel structure of a radio frequency tag design that is thin and flexible. The tag has the antenna and all interconnections placed on a single plane of wiring without crossovers. The elements of the package are placed adjacent to one another, i.e., they are not stacked. Elements of the package, the substrate, antenna, and laminated covers, are flexible. The elements are all thin such that the total package thickness including covers does not exceed that of an ISO standard credit card. The resulting tag package, comprised of thin, flexible components arranged and connected in a novel way, is also thin and flexible. Accordingly, this enables a novel range of applications that include: RF ID tagging of credit cards, passports, admission tickets, and postage stamps.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1, comprising FIGS. 1A and 1B, is a drawing showing the cross section view of two typical embodiments in the prior art.

FIG. 2 is drawing showing a cross section of one preferred embodiment of the present thin RF ID tag.

FIG. 3 is drawing showing a cross section of one preferred embodiment of the present thin RF ID tag with an aperture in the substrate.

FIG. 4 is a top view of the thin tag showing a dipole antenna.

FIG. 5 is a top view of a thin tag having more than one folded dipole antennas.

FIG. 6 is a top view of a thin tag having a battery included in the circuit.

FIG. 7 comprises FIGS. 7A-7E which are cross sections of prior art chip bonds to substrates by means of thermo-compression bonding (FIG. 7A), ultrasonic bonding (FIG. 7B), C4 solder bonding (FIG. 7C), conducting adhesive bonding (FIG. 7D), and spot welding (FIG. 7E).

FIG. 8 shows a thin tag used as a postage stamp.

FIG. 8A shows a thin tag enclosed in a parcel membrane or in the wall of an envelope.

FIG. 9 shows a thin tag placed in the cover of a passport using a resonant loop antenna.

FIG. 10 shows a thin tag used on an admission ticket.

FIG. 11 shows a thin tag used as an antitheft device.

FIG. 12 shows a thin tag placed inside a credit card.

FIG. 13 shows a thin tag placed inside a license.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 2 shows a side view of a novel RF ID tag 200. The chip 210 is located on a flexible substrate 220. The chip 210 with bumps 225 on contacts 222 is bonded to an antenna 230

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contained on the substrate 220. The package is sealed by thin flexible laminations 270 consisting of a hot-melt adhesive 250 such as EVA on the inside and an outer coating 260 of a tough polymeric material on the outside.

The antenna is manufactured as an integral part of the substrate. It will consist of thin, typically 25 to 35 micron thick copper lines which have either been etched onto a copper/organic laminate or plated on the organic surface. The thinness of the copper maintains the flexibility of the substrate. Typical materials used are polyester or polyimide for the organic and electroplated or rolled annealed copper. The copper may be gold or tin plated to facilitate bonding. The chip is connected to the antenna lines by means of bumps on the chip, either plated gold bumps for thermo-compression bonding or C4 solder bumps for solder bonding are preferred. The bumps 225 then become the connecting lines. Since they are only on the order of 25 microns or so they will not degrade electrical performance by introducing unwanted inductance into the circuit. The novel design has a single metal layer with no vias (between-plane connectors through a dielectric layer) in the flexible continuous film. By using only one level of metal to produce the antenna and interconnections, the package is kept thin. Further novelty of the invention includes arranging the components (chip and antenna and possibly a battery) in adjacent proximity to one another. This means that the components are close (i.e., not stacked). In a more preferred embodiment the closeness is insured because the chip 210 is bonded directly to the antenna 230 without the use of crossovers in the circuit. This is accomplished by using either a dipole, loop or folded dipole antenna that is resonant rather than using a multiloop antenna which requires cross-overs for connection. Thus all of the wiring is placed in a single plane. Keeping the antenna adjacent to the chip, avoiding cross-overs and stacking, also contributes to keeping the package thin.

To maintain the thinness of the package, the chip is made to be 225 to 375 microns thick by thinning. In general, semiconductors are manufactured on thick wafers, up to 1 mm thick. Thinning may be done by polishing or backgrinding of the wafer after manufacture. All elements and bonds are very thin. The elements are preferably: the chip (and battery if used) are 10 to 12 mils (250 to 300 microns) thick or thinner; the bonding structures are 2 mils (50 um) or less; laminating materials 2 to 4 mils (50 to 125 um) per side; to produce total thickness preferably of about 20 mils (500 um) or less but in any case less than 30 mils (750 um). Bonding mechanisms do not add to thickness of the tag as would techniques like wirebonding.

Although not required in one preferred embodiment, a unique flexible covering material 270 may be laminated upon one or both sides of the package. In another preferred embodiment, the material consists of two layers (250, 260). A soft copolymer such as ethyl-vinyl-acetate is located on the inside 250 surface of the cover. Tough polyester is located on the outside 260 surface. This combination provides environmental protection while maintaining the flexibility of the package. Typical thicknesses of the covers range from 50 to 125 microns. Alternately, a single layer of laminate such as polyethylene, polyester, mylar or polyimide may be used for covering.

FIG. 3 shows a side view of a unique RF ID tag 300. The chip 310 with contacts 322 and bumps 325 is bonded to antenna 330 thru window 315 in substrate 320. In a more preferred embodiment, encapsulant 340 is used to protect the chip 310, the bonds 325 on contacts 322, connected to antenna 330 located in window 315 between substrate 320 from environmental exposure. In a still more preferred

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embodiment, the package is sealed by thin flexible laminations 370 consisting of hot melt adhesive 350 such as EVA, phenolic butyral, or silicone adhesive on the inside and an outer coating 360 of a tough polymeric material (such as polyester, mylar, polyimide, and polyethylene) on the outside. In an alternative preferred embodiment, layer 370 comprises a single layer of organic material.

In order to further reduce the thickness of the package, the substrate is manufactured with a window allowing the insertion of the chip into the window. Thus, the thickness of the substrate is not added to the thickness of the chip. The window is produced in organic materials, polyimide or polyester by either etching or punching. In addition, the window may be used to allow the coating of the chip with a thin layer of encapsulation material. Hysol epoxy 4510 is one such material. The encapsulant does not add substantially to the total package thickness, adding perhaps 50 microns, but does provide additional environmental protection for the chip. Opaque materials in the encapsulant protect light sensitive circuits on the chip. In this embodiment, the antenna and the center of the chip can be coplanar.

FIG. 4 shows a top view of the thin RF ID tag 400. The chip 410 is located within a window 450 placed in a flexible substrate 420. The chip 410 has contacts 425 which are connected to an antenna 430 contained on the substrate.

FIG. 5 shows a top view of the thin RF ID tag 500. The chip 510 placed in the window 550 has contacts 525 which are connected to more than one folded dipole antenna 530 and 531 contained on the substrate.

FIG. 6 shows a top view of the thin tag 600. The semiconductor chip 610 is connected to a folded dipole antenna 630 by means of contacts 625. The antenna is contained in the substrate 620 as described above. A thin battery 660 is connected to the chip 610 by leads 661 and 662 bonded at contacts 625.

The battery has short connecting lines 661 and 662 providing electrical continuity between the battery and the chip. The battery is placed adjacent to the chip, not stacked upon the chip. The battery thickness of about 0.25 mm keeps the battery flexible. The antenna is designed such that it is also adjacent to the battery. There is no overlap. The wiring is kept in one plane and all of the elements (chip, battery, antenna) are coplanar; there is no stacking. As a result, the package is thin and flexible.

The bonding method for attaching batteries to prior art radio frequency tags include some of the techniques described below, i.e., soldering, conducting adhesive; and wire bonding. In addition, spot welding may be used. In spot welding, shown below in FIG. 7E, the battery connection pads are pressed to contacts on the substrate while a low-voltage high-current pulse bonds the two metals together.

In one preferred embodiment, the metallurgies on the battery, chip, and substrate are such that the battery attaching mechanism is consistent with the method and mechanism of the chip attachment. For example, use of tin plating on the substrate to enable chip bonding may preclude use of conductive adhesive to attach the battery but might allow use of gold plating to enable attaching of both.

A more preferred embodiment used to make a thin flexible rugged package uses robust chip attach techniques such as thermocompression (TC) bonding used in TAB (tape automated bonding) technology. Using TC bonding for the chip and spot welding for the battery is a novel combination of bonding techniques that enables attachment of the battery to a flexible substrate 620. In one preferred embodiment, the substrate is a TAB polyimide or polyester.

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FIG. 7 shows different types of bonding available in the prior art to attach chips to circuitry that are on the substrate when producing an RF tag. These include thermocompression bonding, ultrasonic single point bonding, soldering, and conductive adhesive.

In FIG. 7A, using thermocompression bonding, suitable metal surfaces are brought into contact with pressure 750 and heat 740 applied by thermode 720 to form a metal-to-metal bond 760 usually gold bumps 730 on chip 710 to gold-plated leads 706 on substrate 705 which rests on lower thermode 780. Many leads are bonded at once (gang bonding). This is used extensively for reel-to-reel TAB (tape automated bonding).

FIG. 7B shows ultrasonic singlepoint bonding a variation on thermocompression bonding for TAB where some ultrasonic energy is substituted for some pressure. One bond is done at a time. This bonding type also requires gold-to-gold metallurgy. Bonding tip 751 applies pressure 731 and ultrasonic energy 741 while pressing lead 721 to bump 725 on chip 711 resting on lower support 705.

FIG. 7C shows soldering or C4 solderbonding where small lead/tin solder bumps 746 are used as the connecting medium between chip 716 and pads 726 on substrate 736. The reflow is carried out while the substrate is carried on platform 756 through oven 786. This usually requires the application of solder flux for reflow of the solder at elevated temperature.

FIG. 7D shows conducting adhesive bonding where a metal-filled adhesive 744 is applied to form the connecting medium between chip pads 740 on chip 714 and the substrate pads 724 on the substrate 734. Heat 774 and pressure 784 are applied by pressing between thermodes 764 and 754.

FIG. 7E shows spot welding where welding tips 755 and 765 separated by gap 775 are pressed to conductor 745 held in contact with conductor 735 placed on insulating substrate 725. Current 785 heats the welding tips 755 and 765 to make the bond.

FIG. 8 shows an RF postage stamp 800 containing a thin RF tag 810 which consists of antenna 815, battery 820, and chip 830 affixed to envelope or package 840. This tag 810 can be any of the embodiments described above. In this application, the cover (typically 270 of FIG. 2 and 370 of FIG. 3) for the tag is the paper of the stamp. Adhesives, such as acrylics, are used to sandwich the tag between thin paper. These adhesives would correspond to the layer 250 in FIG. 2 and 350 in FIG. 3. The top surface (of one side 270, 370) can be printed with the appropriate graphics while the bottom surface has a pressure sensitive adhesive (of the other side 270, 370 in the case of a tag laminated on two sides), also acrylic, to bond the stamp to a package or letter envelope. The RF tag would contain information about mailing used to track a letter or parcel on which the stamp is placed. Alternatively, the RF tag 850 could be enclosed in the parcel membrane or in the wall of the envelope 840. In another, embodiment the RF tag could be placed within the parcel or envelope.

FIG. 9 shows the thin RF tag 920 embedded in the cover 910 of passport 930 to form an RF passport 900. Here the tag is sandwiched between the paper covers of the passport. The tag can have an environmental laminate(s) (270, 370) as described above or alternatively, the passport cover can be used as the tag laminate(s) (270, 370). The tag contains in its memory information on the identity of the passport owner, visas, dates of entry, restrictions, or any other desirable information. The information may be in encrypted form for added security. The encryption "key" would be a software

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code that is held and used solely by the agency issuing the passport. The decryption key may be made public so that anyone (with a public decryption key) can read information in the memory of the tag but only the agency having the encryption key can write information to the tag.

FIG. 10 shows admission ticket 1010 containing RF tag 1020. The tag is again enclosed between paper covers or other laminates. The ticket may be a simple admission ticket or entitlement such as an airline ticket or a food stamp. However, the tagged ticket may also serve as a tracking device.

FIG. 11 shows a CD 1140 enclosed in box 1120 with an RF ID anti-theft tag 1130 affixed to the box 1120. The tag serves as both a barcode replacement, inventory device, point of sale device, and as an anti-theft device. Information on product variety, price, date of manufacture and sale may be carried by the tag. Additional bits of information in the memory of the circuit may be changed at the time of sale to indicate that the item may be taken from the store.

FIG. 12 shows ISO standard credit card 1210 containing an RF tag 1220. The credit card may serve as an ATM card, frequent flyer card, library card, phone card, employee ID, medical ID card, gasoline credit card or any credit or debit card. The covers (laminates 270, 370) of the tag could be the covers of the credit card, preferably PVC laminations. The core of the credit card, 0.5 mm thick, has a window placed in it at the time of manufacture. The 0.5 mm thick tag package is placed in the window and then sealed into the card. The resulting credit card, including the tag, will not only have the length and width that meet the ISO standard, but the thickness as well.

In another embodiment of the present invention, shown in FIG. 13, the RF tag 1320 is placed within a vehicular drivers license 1310 in the same manner as described above. This allows information on the RF tag to be used for personal identification, driving record, organ donor information, restrictions, proof of identity and age, etc. The information can be encrypted for security purposes.

We claim:

1. A thin flexible electronic radio frequency tag circuit comprising;

- a. an insulating, flexible substrate;
- b. an antenna that is an integral part of the substrate and that has terminals;
- c. a circuit chip having a modulator circuit, a logic circuit, a memory circuit, and chip connectors and being on the substrate in adjacent proximity to the antenna;
- d. one or more connecting lines between the antenna terminals and the chip connectors, the connecting lines being coplanar with the antenna and antenna terminals.

2. A circuit, as in claim 1, wherein the substrate is organic.

3. A circuit, as in claim 2, wherein the substrate is polyimide.

4. A circuit, as in claim 2, wherein the substrate is polyester.

5. A circuit, as in claim 1, wherein the connecting lines are bonded to the chip connectors using any of the bonding types including thermal compression, single point bonding, C4 bonding, and conductive adhesive.

6. A circuit, as in claim 1, wherein the substrate has an aperture into which the chip is placed.

7. A circuit, as in claim 1, wherein the chip is covered by an encapsulant.

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8. A circuit, as in claim 7, wherein the encapsulant is opaque.

9. A circuit, as in claim 7, wherein an organic cover surrounds the chip, the encapsulant, the substrate, and the antenna.

10. A circuit, as in claim 9, wherein the organic cover is one of the materials including polyester, mylar, polyimide, and polyethylene.

11. A circuit, as in claim 1, that is laminated by one or more layers.

12. A circuit, as in claim 11, that is laminated by a two layer laminate comprising a hard outer layer and a adhesive inner layer.

13. A circuit, as in claim 12, wherein the adhesive is one of the materials including ethyl vinyl acetate (EVA), phenolic butyral, and silicone adhesive.

14. A circuit, as in claim 11, wherein the circuit is laminated on one side.

15. A circuit, as in claim 11, wherein the circuit is laminated on two sides.

16. A circuit, as in claim 11, wherein the circuit has at least one tag dimension that is less than 760 microns (30 mils).

17. A circuit, as in claim 16, that is encapsulated as an International Organization for Standardization (ISO) standard credit card size package.

18. A circuit, as in claim 1, wherein the antenna is a resonant antenna and is any one of the following structures including folded dipole, dipole, and loop.

19. A circuit, as in claim 1, wherein a battery is also affixed to the substrate in adjacent proximity to the antenna and chip and is connected by one or more battery connecting lines to two or more chip battery contacts wherein the battery connecting lines and the battery contacts are coplanar with the antenna and connecting lines.

20. A circuit, as in claim 19, wherein the battery contacts are connected to the battery connecting lines by any of the bonding types including spot welding, soldering, thermocompression bonding, and conducting adhesive.

21. A circuit, as in claim 19, wherein the battery contacts are connected by spot welding and the chip contacts are connected to the antenna by thermocompression bonding.

22. A circuit, as in claim 1, wherein the chip has at least one chip dimension less than 300 microns (12 mils), the antenna has at least one antenna dimension less than 35 microns (1.4 mils), and the substrate has at least one substrate dimension less than 125 microns (5 mils) whereby the circuit has at least one circuit dimension less than 508 microns (20 mils).

23. A circuit, as in claim 22, wherein the chip memory has information about mailing and the circuit is applied to a mailed letter or parcel.

24. A circuit, as in claim 23, wherein the RF tag is enclosed within a stamp.

25. A circuit, as in claim 23, wherein the RF tag is enclosed within the parcel or envelop membrane.

26. A circuit, as in claim 22, wherein the tag is enclosed in a passport.

27. A circuit, as in claim 22, wherein the tag is enclosed in an admission ticket.

28. A circuit, as in claim 22, that is enclosed in an article and the tag has information to prevent theft.

29. A circuit, as in claim 22, wherein the tag is enclosed in a drivers license.

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